INTRODUCTION

This essay has two parts.

Part II reproduces in substance a lecture, "Albert Einstein, how he was and what he did," given on the Rice University campus on March 14, 1979, in commemoration of Einstein's hundredth birthday. It is an analysis of Einstein's achievements in physics, terrestrial and cosmological; of his mode of originality; of his impact both on physics and on philosophy; and, importantly, of his resistance to certain innovations in physics that came after his. The lecture harmonizes certain features of Einstein's intellectual constitution, scientific and general, by viewing him as a personage with intellectual roots in and flowering fully in the ambience of the nineteenth century. It is true that Einstein's high creativity falls into the period 1900-1920. But—as was stipulated in the lecture, and will be observed throughout the essay—our nineteenth century is deemed not to end in 1900 but to extend till after World War I, so that our twentieth century (proper) begins only then, that is, not much before 1920. This is not at all an *ad hoc* postulate. This manner of separating the two centuries has been burrowing in my thinking for a long time and has surfaced, insinuatingly and demandingly, in the present context. Still, Einstein did enjoy enormous applause and a raptly listening audience in the "true" twentieth century, so that he was indeed situated "between centuries," as is signified in the title of the essay.

Part I creates a setting for Part II, but has an identity of its own. It offers divers observations on developments in the nineteenth and twentieth centuries that widen out Einstein's topics in physics into themes in intellectuality at large. The physical topic of general relativity subsumes itself under a comprehensive theme of "Space and (geometric) Structure"; and the subject matter of quantum theory, "old" and "new," that deeply influenced Einstein's career from first to last, is part of a universal theme of "Comparisons and Contrasts between the Continuous and the Discontinuous (or the Discrete)." The theme of Space and Structure has been, in my view, highly creative since the end of the Middle Ages, and the theme of Discontinuity versus Continuity clearly goes back to classical

antiquity. But in the present context we will concentrate on developments since 1800, and my presentations will of themselves justify this restriction. Also, I will round out Part I with some observations that may not visibly bear directly on Part II.

Our leading theme in Part I will be Continuity and Discontinuity, because it gives rise to a significant distinction between the two centuries, the nineteenth and twentieth. Nineteenth-century physics created a major theory on this theme, the statistical theory of matter. But in this theory as everywhere else, the century gave considerable presumptive preference to Continuity over Discontinuity. As will be explained in Part II, however, in the twentieth century, after Einstein had peaked, physics took a sharp turn towards giving recognition to discontinuity, much to Einstein's abiding but futile chagrin. This turn towards discontinuity was a momentous development, gloriously forward-directed, and the twentieth century can take pride in this rare mark of superiority of strength over the nineteenth. It is an aim of Part I to extend this complex of presumptions and insights from the confines of physics into open areas of intellection, showing how the Continuous and the Discontinuous are becoming evermore equipoised. Immanuel Velikovsky's *Worlds in Collision* (1950) endeavored to identify large-scale discontinuities in very recent behavior of our planetary system. Academic professionals were scandalized by this work, but it subsumes under our general theme nonetheless.

We will not start Part I with a blunt assault on my primary theme. Rather I will ease into it after presenting striking instances of nineteenth century originality. That the nineteenth century had an originality *sui generis* readily suggests itself by the following: Carl Becker in a small but unforgettable book, *The Heavenly City of Eighteenth Century Philosophers* (1932), could propose that, on the whole, the intellectual attitudes of that century were medieval rather than modern, Voltaire or no Voltaire.[1] But no such pull-back of the nineteenth century to a previous one is on record, or is likely to be proposed in earnest. At any rate we will find that the nineteenth century was the first to overcome certain impedimenta, technological and scientific, that had persisted since Antiquity, right through the Middle Ages, the Renaissance, the Scientific Revolution, and the Age of Enlightenment.

For mathematics I have anticipated this in a previous essay, "The Emergence of Analysis in the Renaissance and After."[2] We there found that, in the age of the Renaissance, mathematics came under the rejuvenating dominance of suddenly emergent Analysis; that "the three centuries 1500-1800 in the rise of modern mathematics 'genetically' correspond to the three centuries 500-200 B.C. in the rise of Greek mathematics, . . . but that this genetic correspondence breaks down after the terminal dates, totally and irretrievably."[3] After 200 B.C., Greek mathematics began to slide down, slowly but inexorably, towards an extinction in its own phase; whereas in modern mathematics after 1800 phenomena of "firstness" came to the fore analogous to those in fields of

science and technology. In the present context I will not give to mathematics a precedence of description, but let it find its turn in due course.

Among the differences between the nineteenth and twentieth centuries there is a "sociological" one, which can be presented immediately now, however elusive and contestable it be. The difference is that the twentieth century has not produced anybody of the truly universal standing and recognition of an Einstein, Freud, Tolstoy, Darwin, or even Karl Marx. To be sure, in the twentieth century there are counterparts to them who have profoundly influenced our world, lives, and fortunes. But their acclaim and recognition come more from professional confrères than, as in the nineteenth century, from the public at large. Heisenberg and Schrödinger, the creators of the new quantum theory, have received a good deal of applause. But how many people know that Heisenberg, at least in his youth, played the piano almost like a stage artist, probably much better than Einstein his fiddle; or that Schrödinger struggled with the problem of the role of physics in biology, something Einstein never was concerned with? Kurt Gödel created in 1931 a law in logic[4] that would do honor to Aristotle (we will have occasion to invoke it towards the end of Part II). But who cares to know whether there is a baby photograph of Gödel around?

In sum, it seems to me that Einstein was the last representative of a species of folk heroes that is presently extinct, or at least invisible. And I do not quite know why this should so be, unless I accept Spengler's pronouncement that, in the West, the twentieth century would be epigonic to the nineteenth.

This one difference between the two centuries is perhaps more striking than profound; but there will be substantive ones too.

NOTES

1. See my article "Mathematics in Cultural History," *Dictionary of the History of Ideas* (New York, 1973), vol. III, p. 179.

2. In "History of Analysis," *Rice University Studies* **64**, nos. 2 & 3 (Spring-Summer 1978): 11-56.

3. Ibid., p. 15.

4. I mean the so-called "incompleteness theorem," that if a formal logical system is expressible within the arithmetical language ordinarily taught in secondary schools, then it includes assertions which can be neither proven nor disproven. See Andrzej Mostowski, *Sentences undecidable in formalized arithmetic; an exposition of the theory of Kurt Gödel* (Amsterdam, 1952).

PART I

NINETEENTH- AND TWENTIETH-CENTURY BACKGROUND

In 1803 the Reverend Samuel Miller, Trustee of Princeton University, published a *Brief Retrospect of the Eighteenth Century* that, even though an intended second volume never appeared, was anything but brief. In the judgment of the critic Gilbert Chinard, Miller's survey found that the eighteenth century was, among other things, "the age of literary honors and of international memberships in learned societies, and the age of literary and scientific intercourse, for while in all preceding ages literary men were in great measure 'insulated,' increased facilities in transportation have enabled them to travel and to communicate freely."[1] Our own retrospect of the nineteenth century will indeed be very brief. It will begin with pointing out how incomparably *more* innovative travel and communication since 1800 have become, and what the consequences of this have been; and this will set the tone for much that will follow.

1. TRANSPORTATION, COMMUNICATION, ILLUMINATION

When in 1812 Napoleon and his *grande armée* set out to conquer Russia, their basic mode of travel was the same as that of Caesar and his legions when setting out to conquer Gaul: on foot, on horseback, and in wagons. By now the horses had shoes, the riders had spurs, and some of the wagons were spring-cushioned coaches. But horse-drawn vehicles they were. And when retreating from General Kutusov, Napoleon traveled the same way as Darius when fleeing from Alexander the Great. Also, Napoleon's overland postal service was not much different from Darius'. For urgent pithy messages he might have conceivably still used beacons of fire as did Aeschylus in his *Agamemnon*. Papal conclaves are still signaling by columns of smoke.

But in the middle of the nineteenth century the American Civil War was suddenly fought by railroad and Morse telegraph; at the end of the (extended) century, in World War I, military planes met in dogfights; and already, years

before, there were wireless communications ship-to-shore and ship-to-ship. After that, the twentieth century made transport by plane and communication by satellite a way of life.

In the wake of such strides in transportation, the nineteenth century did not limit itself to the creation of "learned" societies for a "select" few as Samuel Miller boasted for the eighteenth century, but there sprang up, all over, various academic and professional societies, whose membership comprised all those engaged in a certain kind of activity. Societies like these began to hold annual, or even more frequent, meetings to which the *total* membership was invited; and, very significantly, towards the end of the nineteenth century, international congresses for ever-larger numbers of participants began to be organized, sometimes with telling results. For instance, in 1904 Henri Poincaré proclaimed his Relativity Principle not in Paris, where he was domiciled, or even in France, or even in Europe, but in the U.S.A., at the World's Fair in St. Louis, at something called the International Congress for Arts and Sciences.

In the twentieth century, scientific meetings and conferences—local, regional, national, and international—have become a rage, and scientific collaboration, even outright research collaboration, by long-distance telephone is a common occurrence.

Furthermore, the history of the rise of Socialism, Communism, Nihilism, and Anarchy in the nineteenth century is replete with accounts of various travels of partisans, either among themselves or to formal gatherings. These travels became increasingly frequent as the century progressed, and "Internationals" and "Congresses" proliferated. Karl Marx made his true debut in 1864, at a meeting of the so-called First International, whose full name was The International Working Men's Association. It was set up in London in 1864, began as a joint affair of the British and French Trade Unions, and subsequently organized Congresses, Conferences, and Sections in various European cities like London, Geneva, Lausanne, Brussels, and the Hague.[2] Marx and Marxism would hardly have come to influence and power without these propagandistic outlets.

The crowning event of "The Rise of Communism by Travel Facilities" came in 1917, during World War I, when Germany's General Erich Ludendorff outwitted himself monumentally by transporting Lenin from Switzerland to Leningrad, then St. Petersburg, in a sealed railroad car right across Germany, with the avowed aim of overthrowing the czarist regime.

In the twentieth century ease of travel has vulgarized life. Even before 1890, Jane Harrison, author of *Prolegomena to the Study of Greek Religion* (1903), an academic nurse to a generation of lustrous classicists, braved great difficulties when going to Athens for topographic studies of its ancient precinct and for visiting the birthplace of Zeus in a cave of the lonely island of Crete. Nowadays these places are overrun by organized tourist groups. The Tahiti

of today is not the Tahiti of Matisse. And an American, fleeing an island off New England for an island off Spain, winds up with the same Coca Cola bottle in hand.

Quick travel and communication call for adequate nighttime illumination, and it was an important modernism when in 1784 Aimé Argand put a glass chimney around the wick of the oil lamp.[3] Nevertheless, in its beginning, the nineteenth century was still very close to age-old candlelight, flickering as ever. Balzac (1799-1850), for instance, wrote still by candlelight, working through many a long night. But the century spent most of its productive years by cheerful kerosene lamps and ever-shining gas burners, and many bulky scholarly works bear the hallmark of this effective innovation.

It is surprising to find, day in and day out, how many of these nineteenth-century "gaslight" works either do not have any adequate successor works in the twentieth century, or, at least, refuse to be superseded by them; and so they have to be reprinted, in ever increasing numbers, for active research and reference activities. There are very few reference books in continuing use that were written before 1800, but astonishingly many from the nineteenth century are still flourishing. Moritz Cantor's voluminous *History of Mathematics* is a reference work in active use, and so is Eduard Zeller's comprehensive *History of Greek Philosophy*. In 1874 Alexander Schmidt, a sickly Prussian schoolmaster in Koenigsberg, who apparently had never set foot in an English-speaking land, compiled a Shakespeare dictionary that is still on American reference shelves. The British "Liddell-Scott," in an up-dating, is *the* dictionary of classical Greek all over the world. Emile Littré compiled not only his renowned *Dictionnaire de la langue française,* but, being a physician by training, he also compiled an indispensible many-volume edition of the Greek Hippocratic corpus, with translation, commentary, and essays. With all that, he also spread the gospel of Auguste Comte's positivism among "machine" politicians, making himself one of them. The grand *Oxford English Dictionary* appeared. And there is always the eleventh edition of the *Encyclopedia Britannica* (1911), challenging anybody to dare turn it to pulp with which to produce a would-be better edition of the work.

In the twentieth century, many-volumed academic works, scientific and humanistic, tend to become "corporate" or "collective," that is, to become collections of contributions by *soi-disant* specialists. In the sciences, physical and social, even research work and its publication are done with increasing frequency by two or more authors jointly. In the nineteenth century people were clannish and socially gregarious, but did "brain work" individually, by themselves. In the twentieth century they are members of Margaret Mead's nuclear family and David Riesner's lonely crowd, but do their brain work jointly.

In consequence of this development, standards for originality of achievement by an individual may become harder to apply. Einstein himself became involved in a minor identity problem resulting from joint authorship. Around 1913, on the road to the theory of general relativity, he and the mathematician Marcel Grossmann had written a few joint papers on the mathematics that was prerequisite for the eventual theory. It is reported that in later years Einstein insisted that the joint work was only a convenience to him, and that he could have managed without it.

Jointly authored research in mathematics, physics, and other sciences began to multiply after the late Victorian era, and it frequently came into being in the coffee houses in which academics congregated. Europe before World War I was a vast peninsula of the Eurasian landmass teeming with coffee houses. Mathematicians, for instance, did a good deal of joint work there, but some others did not. Jean Paul Sartre and Simone de Beauvoir, the longest-surviving fossils of the coffee-house era, have not been known to cooperate literally, either between themselves or with others.

2. THE AGE OF THE EARTH AND OF THE UNIVERSE

A drastic change of outlook between the two ends of the nineteenth century took place with regard to the age of the earth, affecting the questions of the chronology of the earth and of the scientific standing of the Biblical account of creation as given in *Genesis.*

Around A.D. 1800, it was still presumed that the time that had elapsed since the last flood, Noah's Flood—the occurrence of which, in one form or another, was somehow taken for granted—was around six thousand years, as implied in the Biblical account that had been composed around 700 B.C.[4] It was already taken for granted, though, by church fathers and their Jewish counterparts, that creation itself had taken place appreciably earlier, the six days of creation having been six epochs of events and not just six days in our conventional sense. Even so, around 1800 the *total* age of the earth was not thought to be very great. The last generally known chronological enumeration before 1800 had been made in 1778, in Georges de Buffon's *Epochs of Nature*, in which he distinguished several epochs: from the creation of the earth as a hot nebula to its consolidation, hence to its cooling-off, hence to the beginning of organic life, hence to the creation of man, and hence to the present. With all these various epochs to account for, the total age of the earth ran only into one hundred thousand years or so.[5]

But at the other end of the century, in 1906, a calculation was made by which the age of the earth was estimated to be at least a *billion* years old. Radioactive decay was a recent discovery then; and the physicist B. B. Boltwood, an exceedingly quiet American, was apparently the first to suggest, in correspondence with Ernest Rutherford, that the element lead in the earth had arisen by decay from uranium. At least a billion years would have been needed for the total process to come about; Boltwood thus hinted indirectly at a minimum age for the earth.[6]

Between Buffon and Boltwood there were of course estimates running into millions of years "only." The first paragraph of the National Research Council's study, "The Age of the Earth," runs thus:

> At the beginning of the present century the problem of the age of the Earth was envisaged as requiring the reconciliation of three independent estimates, all of the same order of magnitude. These estimates were G. H. Darwin's, of 57 million years, based on the separation of the moon from the earth; Lord Kelvin's, of 20-40 millions, based on the secular cooling of the globe; and Joly's, of 80-90 millions, based on the rate of accumulation of sodium in the world-ocean. To these should be added Helmholtz's estimate of 22 million years, based on the source of the sun's heat and its probable duration.

These intermediate estimates came very late in the nineteenth century, in the last third of it, and apparently only after the publication of Charles Darwin's *Origin of Species*. This work finally liberated the average scientist from the necessity of comparing the scientific account of the age of the universe with the Biblical one. Until then, the geologist somehow had to take a stand with regard to the Biblical account, and it was more admissible to oppose it than to ignore it. The requirement that science be answerable to religion was one of the longest-lasting survivals of antiquity into modern times. The nineteenth century finally succeeded in loosening scientific ties to theology that the Renaissance, and even the mighty Scientific Revolution after it, had not. Since Darwin's *Origin*, anybody who still considered himself scientifically accountable to the Bible has been called a Fundamentalist.

Helmholtz, and also some of the others, were wondering not only how old the earth is, but also how long life on it, which obviously depends on a steady supply of heat, is likely to continue. Buffon had already made an estimate. He greatly underestimated the heat coming from the sun, and took into account mainly the heat that reaches the habitable earth by propagation from the hot center of the earth. This is little enough. In addition to that, Buffon's calculations, which came before J. Fourier's great treatise on the propagation of heat, were inexpert. Even from his own premises, Buffon's estimate for the future of life on earth was shorter than it might have been.

Helmholtz and his contemporaries knew, of course, that the energy reaching us from the sun is the decisive figure in the calculations, and the question before them was how the sun's heat can maintain itself, and for how long. Only two large-scale sources for production of heat suggested themselves to them, chemical combustion and mechanical motion. They examined both, the mechanical motion being that of the sun itself, of meteorites, and of other cosmic matter attracted by the sun. Their hypotheses allowed for millions of years only, both in the past and for the future life of the earth,[7] but paleontological and related estimates called for billions of years instead.

The microphysics of the twentieth century finally brought relief. Close to 1940 it was suggested that the production of energy in the sun is an atomic process converting hydrogen into helium; such a process does allow for

billions of years, past and future. A great irritant of the nineteenth century was removed.

Otherwise, the twentieth century has raised Boltwood's estimate of over a billion years for the age of the earth to several billion, which is not much of a change, and big-bang theories of creation have assessed the age of the universe to be ten to fifteen billion years.

The preceding account owes much to a conversation with the Rice geologist John Allan Stewart Adams.

3. PROBING THE GALACTIC UNIVERSE

William Herschel in the eighteenth century felt that all the pursuit of astronomy required was bigger and better telescopes, and still in 1857, G. F. Bond of Harvard opined "that it was simply a matter of finding one or two hundred thousand dollars."[8] Actual developments proved the problem was not so simple.

The nineteenth century created spectroscopy[9] and laid the foundation for radio astronomy. These are powerful searchlights for the exploration of the telescopic depth of the universe that had been bared in Galileo's *Starry Messenger*. The nineteenth century readied both devices, and began to test spectroscopy seriously. The twentieth century has been developing and using both of them to the hilt. They complement each other to such an extent that radio-astronomy is forgiven if, somewhat irreverently, it has taken to calling its "big dish" a radio-telescope.

These devices derive their power from living on Maxwell's vast electromagnetic spectrum that stretches from frequency 0 to frequency ∞—a discovery that was as great a hallmark of the Victorian Age as any. Spectroscopy resides in the visible part of the spectrum, Newton's domain, and radio waves emanate from its nethermost part, the realm of Heinrich Hertz. The uppermost part is also sending messages, unsolicited ones, via cosmic rays, but they have not yet been unscrambled.

Spectroscopy can identify the composition of matter, say its chemical composition on earth, in the solar system, and anywhere beyond. That is, it can say what stars are made of in defiance of Auguste Comte's *obiter dictum*, "the field of positive philosophy lies wholly within the limits of our solar system, the study of the universe being inaccessible in any positive sense."[10] The discoveries came about gradually at first, then the pace quickened. The eighteenth century was in awe of Newton's spectral resolution of sunlight, but did nothing to continue the work. Punctually in 1800, however, William Herschel discovered the infrared; in 1801 J. W. Ritter discovered the ultraviolet; and in 1802 Wollaston was the first to discover in Newton's spectrum certain dark lines in fixed positions, the so-called Fraunhofer lines.[11]

Spectra, and thin lines in the spectra—the lines being sometimes dark and sometimes bright—can be produced by letting any kind of light, from any

luminous source, terrestrial or celestial, pass through a crystal. It was soon sensed, however inarticulately at first, that the coloration of the spectra and the lines in them, especially the latter, transmit information about the chemistry of the light sources and of the media that the light traverses before reaching the refractive crystals. This is what spectroscopy is all about.

A first high point was reached around 1860 by Gustav R. Kirchhoff, partly in collaboration with R. W. Bunsen. Gathering up preceding developments, he greatly emphasized the possibility of applications "to the chemistry and structure of the suns and stars. His treatment was more complete than that of any of his predecessors, and made a much greater impression at the time on the scientific world."[12] Acting on this precept, the British astronomer William Huggins decided in 1863/4 that certain nebulae, which until then (that is, by mere telescopic examination) were deemed indistinguishable, were partly clusters of stars and partly luminous gas.[13]

The creation of the chemistry of celestial matter was only half of what spectroscopy contributed to the comprehension and exploration of the universe. Another half has come about in the way I will elaborate next, and it was again Huggins who was in the vanguard of developments.

By the time J. von Fraunhofer examined his lines in 1815, there was a general acceptance of the undulatory theory of light of Thomas Young. It was part of Young's theory that the length of the wave varies with the color of the light, increasing from violet to red, and Fraunhofer gave precise figures for the waves of his lines. In 1841 the Austrian physicist Christian Doppler announced the principle—now generally known by his name—that if a source of light, or of any other wave of the same mathematical structure, is in motion relative to an observer, then the period of the waves as received by the observer will be different from the period of the waves as emitted by the source: if the source moves away from the observer the wave becomes longer, if it moves towards the observer the wave becomes shorter. Also, soon after Doppler's work, "the French physicist Armand Hippolyte Louis Fizeau pointed out that to detect the [Doppler-] effect in light, one should not worry about overall color, but should measure the exact position of the spectral lines and note their shift."[14] Here again Huggins scored a first. In 1868 he was able to detect a small shift in the spectral lines of the bright star Sirius and to show that it is moving away from the sun. His figures for the velocity of relative motion were not right, largely because he could train his telescope on the star only visually and not yet photographically. Eventually he pioneered in attaching a photographic lens too.

What Huggins observed in 1868 in the spectrum of Sirius is nowadays called a "red shift"; and this phenomenon and Huggins's conclusion from it were only small tokens of a big thing to come in the twentieth century. Edwin Powell Hubble and others trained huge telescopes equipped with the latest spectroscopic devices on distant nebulae and galaxies outside our own, and

the red shift was observed everywhere and any time. Thus the conclusion imposed itself that our universe as a whole is expanding, and this momentous insight of the twentieth century harks back to something that first happened in the 1850s and the 1860s, in the works of Kirchhoff and Huggins.

Even before Hubble's astronomical discoveries, Albert Einstein had encountered the possibility of an expanding universe from purely theoretical considerations and found it puzzling. Hubble's observational confirmation was welcome, but a philosophical sense of wonderment lingers on.

Radio astronomy is largely a creation of the twentieth century. But an attempt, even if an abortive one, to detect solar waves was made around 1890 by the English physicist Oliver Joseph Lodge (1851-1940), a pioneer in radio communication.[15]

4. SPACE AND STRUCTURE

What follows is less spectacular but more substantive than what has preceded.

"Everybody" knows that in the early nineteenth century an age-wrinkled Euclidean geometry passed scepter and diadem to the young and promising non-Euclidean geometry of Bolyai-Lobachevsky. No revisionist historian can gainsay this, but I venture to qualify it.

The horse-drawn vehicles of Napoleon, which I mentioned in section 1, were not the same as those of Julius Caesar, except that horse-drawn they remained. So also, the Euclidean geometry of Gauss, Monge, and Poncelet in the beginning of the nineteenth century was not the same as that of Euclid, Archimedes, and Apollonius in the third century B.C. But recognizably Euclidean it remained, until Bolyai and Lobachevsky made it recognizably non-Euclidean.

Theirs was only a first start on the road to a new geometry. Nowadays geometry-at-large, especially the geometry in science, is something that happens in space, and space is something for geometry to live in. But it was not so for Bolyai and Lobachevsky. For them, as for Euclid, geometry was something to house axioms (and postulates), and axioms were something on which to erect geometry. Still, in the end, something very avant-garde came of it.

The second start came when, in the middle of the nineteenth century, Bernhard Riemann, ignoring Bolyai-Lobachevsky, introduced a general Hausdorff manifold as an underlying variety; and this being given, he imposed on it a certain geometric structure, named "Riemannian metric (or structure)" after him. It cannot be over-emphasized that the generality of the underlying variety upon which the geometrical structure is imposed is of the essence. It is this that first begat Einstein's General Relativity and Cosmology and still lures the masses to him. In the case of Bolyai-Lobachevsky the underlying

variety remained the same, namely a Euclidean expanse, and only the imposed structure was different; Einstein hardly used it.

Like all great art, Riemann's constructs are "representational" and "abstract" at once. They are representational as intuited, but are swaddled in a layer of mathematics that makes them appear to be abstract. And they are indeed so only by appearance. It is this fusion of representation and abstraction that appeals to the "sophisticates" of our day, be they ever so defiantly apologetic about not understanding the mathematics of it at all.

The geometrical axiomatization *à la* Bolyai-Lobachevsky can also be updated and refined, as we will see. But in comparison with Riemann's vertical edifices, it leads to a vast flatness of abstraction, both monotonous and productive, as flatlands can be.

In order to grasp what the nineteenth century did in this matter, and then what the twentieth century made of it, we must go back to the Greeks; go back to them and accuse them of having brought forth the most freakish kind of geometry possible (freakish from our retrospect, of course). When compared to Riemann's geometry, they had nothing "structural," not only no overall Space Structure, but even no underlying so-called Euclidean Space, on which conceivably to erect a structure. As I have stated repeatedly before,[16] nowhere in their thinking did the Greeks have a background space—that is, a Euclidean E^2 or E^3—as a mathematical object in its own right, prior to configurations to place in it. For instance, it is unthinkable to find a record of Archimedes having given a lecture on "Some properties of Space." Ptolemy did not use the concept either. A planetary path of his was of course lying in his cosmos, and a grand conception it was, but as a mathematical construct it was lying in some kind of indistinct metaphysical Nowhere. This continued throughout the Middle Ages. Although there was an adumbration of background space in the work of Nicholas of Cusa in the first half of the fifteenth century, the concept was still lacking in the thought patterns of Copernicus in the first half of the sixteenth century. Concurrently, there was no mathematically oriented theory of gravitation put forward during that long stretch of time.

A break did finally come, at the very end of the Renaissance in the first years of the seventeenth century, and the protagonist was Johannes Kepler. Suddenly and imperiously he introduced mathematical background space into science—any science—and, in effect, into cognition at large, mathematical and other. I have first stated and elaborated this in detail for the case of astronomy and cosmology,[17] and afterwards for virtually all of mathematics.[18] I hope eventually to gather up all Kepler's achievements into one portmanteau, even his explanation of the retinal image of human vision that is second only to his planetary laws, his pride of prides.

Kepler's planetary laws formed half or even two-thirds of Newton's law of gravitation. I would even say nine-tenths of gravitation, if Kepler had derived the laws tolerably well. But he did not. As it was, he only half-guessed them,

and Newton after him had to provide a derivation. In the context of the derivation, in the *Principia* as a whole, Newton imposed on Euclidean Space a certain structure, nowadays called *affine* structure, by making the space the carrier, at each point, of a vector field, by which to identify velocities, momenta, and forces.[19] Before Newton, Galileo, for all the innovations of his *Starry Messenger*, made no contribution to the creation of mathematical background space. Therefore, his gravitational findings are only terrestrial, and his pro-Copernicus argument requires the lengthy *Dialogue Concerning the Two Chief World Systems* of his most mature years, whereas Kepler got his justification of Copernicus out of the way in his slim post-graduate *Cosmographic Mystery*.

Descartes, between Kepler and Newton, imposed on Euclidean Space a structure prerequisite for the unfolding of Analysis through symbolism and infinitesimal calculus. He himself contributed more to the establishment of the method than to its unfolding; uncannily he made his *La Géometrie* an integral part of his *Discours de la méthode*. As will be emphasized in Part II, in the context of gravitation, this "method" went into action well over a century after Newton, in the work of S. D. Poisson at the beginning of the nineteenth century. Poisson firmly introduced the gravitational potential that changed gravitation from a distance action into a proximity action. After another century this insight of Poisson's guided Einstein through the Riemannian maze towards the goal of a gravitation of his own.

Aristotle insists that everything in Nature and Knowledge runs in contrasts and contrarieties. In addition to the vertically cresting space category of Riemann, we have, by contrast, the horizontally undulating space of Georg Cantor, of set theory fame, who was led to generalize the traditional concept of space until it extenuated into being a general "point set," that is, a general (Cantorian) aggregate, the elements of which are viewed as "points." This conception penetrated into all of mathematics. But it also had a great attraction for the "axiomatics" that was an end-product of Bolyai-Lobachevsky developments, and for the mathematical logic of the Boolean algebra type, also a creation of the nineteenth century. This novel context of mathematical science is the "flatland" previously alluded to.

It is a vast savannah, and it must be vast because it is the breeding and nurturing ground of all the automation, computerization, containerization, etc., that is engulfing us ever more pervasively, changing ever more rapidly by the week, day, and hour. Air conditioning, Xeroxing, even food packaging —they are all domiciled on the same twentieth-century flatland, with Henry Ford's assembly line being perhaps in the vanguard; and artifacts like refrigerators, freezers, and washing machines also occupy a corner of it.

There were harbingers of these modern innovations in the nineteenth century, such as standardizing of clothes, shoes, etc., to fit various customers, rather than having them custom-made individually. Thus the department

store is in a sense only a nineteenth-century forerunner of the twentieth-century supermarket and superdrugstore, which now flourish with it, side by side.

The contrariety just sketched between "vertical" and "horizontal" space in science and technology is not haphazard and inconsequential in the details adduced. It also meaningfully occurs in the representational arts, especially painting; and there I can point to an art book wholly devoted to this subject matter for an implied corroboration of my outlook.[20] Having stated my views before,[21] I will here only hint at the high points, and quote passages from two books not previously cited. The Riemann of modern painting is Paul Cézanne, and our first quotation is as follows:

> it was necessary to abandon (as Cézanne had done) the postulates of Euclidean geometry. This involved the adoption of Riemann's topological schemas, schemas which Cézanne had intuitively lit on in his analysis of the phenomenon of extension in the visible world. The significance of this orientation can best be grasped if we bear in mind the fact that, as against Euclidean geometry based on the notion of distance, Riemann's topology, based on surfaces and elastic curves, tended to show that all fundamental relations can be expressed without recourse to any instrument of measurement. Since matter is extensible and distortable, a circle can become an ellipse or a sphere a convex surface without the loss, in either case, of its initial qualities. Ruling out the notions of rigidity, right angles, straight lines and distance (hence of projective coordinates), this topology deals with forms that can be manipulated and reshaped at will. This explains why the many versions of *Montagne Sainte-Victoire* differ from each other far more than all the replicas and variants of a classical "Adoration of the Magi."[22]

The second quotation is from a book by Kurt Badt:

> Cézanne did not plan space as an empty shell into which he later imported objects, and placed them in a certain relationship to each other, expressed through diminishing size, diminishing clarity and changing color; on the contrary, his essential method of reproducing space was to show solids as convex, as detached and separate from each other or as partially covering each other, in other words by making the plasticity of things manifest everywhere, and by making them overlap.[23]

This sentence of Badt's is reminiscent of the description of a locally Euclidean manifold, which is given by overlapping neighborhoods or by adjoining (convex) polyhedral simplices.

The "flatland" that is contrapuntal to Cézanne's "plateau," together with what is built on the flatland, is the land of Picasso the cubist and much of what followed after him, Picasso's flattest production being his "Guernica." There is even a counterpart to Georg Cantor, creator of the point set; it is not of the same intellectual dimension, but a counterpart: Georges Seurat and his pointillism.

A flattening-out also took place in the geometry stimulated by Bolyai-Lobachevsky. In Euclid, and still very much in Bolyai-Lobachevsky, points, lines, and planes were conceived and defined intuitively, and linked up by two kinds of axioms: geometrical postulates, and general "common notions." In

1900 David Hilbert, in a landmark book, *Foundation of Geometry*, "de-intuitivized" the setting. Points, lines, and planes were not defined descriptively at all, but simply "posited" and linked up by a single kind of axiom from which all relations between them were deductively obtained.[24]

After Hilbert, Ernst Zermelo even flattened out the hierarchical relation between a general aggregate and its elements. Aggregates and their elements became one family of objects, but with a formalized binary relation between them, $a \in b$, read: a is an element of b, subject to suitable assumptions.

Finally, during the last years of the (extended) nineteenth century, the linguo-philosopher Ludwig Wittgenstein, in his *Tractatus* (*logico-philosophicus*), brought together the flattened spaces of (Riemann-) Cantor and (Bolyai-Lobachevsky-) Hilbert in a "logical space" of his own. It is a congeries of logical entities like "facts," "atomic facts," "states of affairs," "propositions," etc., and serves as a (mathematico-) ontological background space to a metaphysical "space" or "universe" of reality. The internal contrasts in this construction are comparable to those in a contemporary museum exhibiting paintings on the flattest of background spaces side-by-side with huge sculptures bulging and thrusting out in all directions.

The Edwardian Era, also called the Belle Epoque, was a matrix of such contrasts, as set down in studies on history of art and culture, and also in Barbara Tuchman's *Proud Tower* and similar works.

5. ATOMS, CONTINUITY

Atoms and Continuity are conceptions from natural philosophy that are thoroughly Greek, pre-Socratic or even older. Also, Atomism was frequently representative of Discontinuity, especially to Aristotle, so that Atom and Continuity were even twin conceptions, of sorts. They were talked about throughout the centuries and millennia, but only the nineteenth century brought them to productive life and even put them at center stage. The Renaissance and the Scientific Revolution had not been equal to this task.

Atom is a Greek word (*átomos*, uncuttable). Atomism was created by Leucippus and Democritus in the fifth century B.C., and it has been agitating Western thought unceasingly since. Yet between classical antiquity and A.D. 1800 atomism was aphoristic; after 1800 it became systematic. Before 1800 it was mostly "talk"; immediately after 1800 it became "fact." Hardly anything that was said between Democritus' time and 1800 was more arresting than what had been said by Democritus himself.

What Democritus said was not just that matter is granulated, which is a trivial observation, or even that matter is not always infinitely subdivisible, which even Aristotle, an opponent of atomism, apparently admitted,[25] but that (i) matter consists of microscopic, that is imperceptible, particles, which (ii) are separated by a void between them, the existence of the void being just

as much a part of the assertion as that of the atoms. Furthermore, (iii) the particles are constantly in motion, (iv) all physical events are some kind of "interactions" between the atoms across the void, and (v) different interactions come about by the fact that different atoms have different structural features that dovetail in different combinations.

These postulates, which are also postulates of the basic physical science of today, have been talked about incessantly since Democritus; but only the nineteenth century, starting immediately after 1800, began to implement them by specific statements which can be adduced in a college textbook of today.

The significance of Atomism was recognized by Aristotle even as he steadfastly opposed it (mainly because he "abhorred" its void). He couched his opposition in terms of the highest respect. After Aristotle, the philosophical system of Epicurus, which had an ethical leitmotif and a social orientation, was built around a physical doctrine of atomism that was obviously derived from Democritus, even if, as tradition has it, Epicurus emphatically denied this and claimed the originality of its philosophical creation for himself. After Epicurus, Lucretius saw fit poetically to enshrine the atomism of Epicurus in his *De rerum natura*, thereby making it immortal.[26]

In the Middle Ages, Islamic philosophy at its height permeated its theological doctrine of the Kalam with a far-reaching atomism, mostly though not exclusively of Hellenic origin.[27] The Latin Middle Ages also speculated on versions of atomism whose objects may have been compounds of the "hard" atoms of Democritus and Epicurus with a "softer" kind of "natural minima" perhaps descended from Aristotle. Giordano Bruno, in the second half of the sixteenth century, also propagated a kind of atomism of little scientific value, harking back to medieval conceptions. In the seventeenth and eighteenth centuries the mechanical theory of a finite system of masses suggested an atomistic outlook on the constitution of matter. Philosophically, a systematic elaboration of this outlook was produced in the second half of the eighteenth century by R. G. Boscovitch; it was of no serious consequence to science, but is prized by some philosophers. Also, in the seventeenth century, Father Pierre Gassendi fused a staunch belief in traditional atomism with a kind of Radical Liberalism to such an extent that victorious Communists of the twentieth century canonized Gassendi to Early Sainthood of Marxism. René Descartes, however, proclaimed a doctrine of the constitution of matter that has no relation to atomism at all.

All this discussion of early theories of atomism becomes quaint, antiquarian, and nostalgic when compared to what happened after 1800. First, the classical theory of chemical compounds was put on a satisfactory basis by the introduction of the twin concepts of atom and molecule, with Dalton, Avogadro, and Prout in the lead, a molecule being defined as a compound of atoms of the same or different elements. This entire development culminated

in the Mendeleev table of 1868, and it is noteworthy that already in 1815 William Prout surmised that all elements are built up of hydrogen.

Second, the theory of electrolysis, as developed by Galvani, Volta, Davy, Faraday, etc., led to the introduction of ions, that is, electrically charged atoms, called cations if the charge is positive and anions if the charge is negative. After that, towards the end of the century a pure indivisible unit of negative electrical charge, called the electron, began to take shape in scientific thinking, and at the very end of the century, in November 1900, Max Planck presented his "quantum" of energy. What followed is the subject matter of Part II of this book.

That was not all. There was still a further atomistic conception, one that was nearest to Democritus' own, and it is the subject matter of the theory of statistical mechanics, or, alternately, of the Kinetic Theory of Gases, two theories that are closely related even if not quite synonymous. This theory is a powerful mathematical paradigm for the study of gaseous and similar matter, which can be viewed as a large assemblage of atomlike particles that move with uniform velocity in all possible directions, collide with each other, and are reflected from walls of containers. Except for a solitary anticipation in the eighteenth century by Daniel Bernoulli, the theory is entirely a creation of the nineteenth century.

Einstein's "juvenilia" were a rediscovery of the elements of this theory on his own.

We now turn to continuity.

Continuity is one of the oldest categories of knowledge, perhaps as old as rationality itself. It is basic, sprawling, and all-pervading. A form of continuity, under one name or another, occurs in mythology and theology, history and philosophy, science and mathematics, psychology and anthropology. Without continuity there can be no awareness of one's inner self or outer setting, or of the all-connecting sensation of time. The Greeks somehow knew all this very early. They had a standard word for it (*synechés*), which was firmly planted in the language and was dominant over occasional synonyms. The word occurs in Homer, and already there it shows signs of becoming an abstract notion.[28]

Continuity occurs in our present-day ordinary dictionary meaning in the ontological poem by Parmenides and, similarly, in the company of related terms, in Aristotle's search for a quantitative paradigm for space and time in the second half of his *Physics*. But it does not occur *anywhere* in the corpus of Greek professional mathematical writing in an intended technical mathematical meaning like that of today (the "today" beginning with the early nineteenth century).

If it were not for the Eudoxian theory of proportions, which in its beautiful clumsiness is a substitute for certain aspects of continuity, I would pronounce

that Greek mathematics was a mathematics without space and without continuity either.

Between antiquity and 1800, Kepler introduced into the theory of conics a Law of Continuity, named by him the Law of Analogy, which was later greatly elaborated by Poncelet in the nineteenth century. Leibniz proposed for all of natural philosophy, not only for mathematics, a Law of Continuity under this express name, which the American philosopher Charles Sanders Peirce in the nineteenth century tried, but failed, to duplicate into a much more ambitious law of *Synechism*. And Newton took recourse to a version of continuity in characterizing absolute time as flowing equably (Latin: *aequabiliter*) without relation to anything external. But when the great mathematicians of the eighteenth century tried to give a specific definition for a continuous mathematical function, they flapped about badly.

In the first half of the nineteenth century Cauchy inaugurated a definition of a continuous function that is still in use in beginners' college texts; and in the second half of the century Dedekind and Cantor finally gave a satisfactory characterization of the linear continuum that Aristotle, to his eternal glory, was passionately searching for. After that, the newly constituted discipline of topology took over. Soon after World War I—that is, at the proper beginning of the twentieth century—it came up with a definition of a continuous function that is "the real thing," however premature it is even today to tax the average freshman with it.

And if our freshman, coming to college full of hopeful expectation, is disenchanted with the technical dryness of the definition of continuity offered to him, then let him consider that this is the only definition of it there is in the wide world of knowledge; or rather that mathematics is the only segment of human knowledge in which a definition of continuity can be rigorously formulated at all. Also, in mathematical contexts continuity is sharply distinguished from neighboring concepts like uniformity, steadiness, constancy, etc., all of which have, in mathematical contexts, definitions of their own. Outside of mathematics, however, in vast reaches of applications, continuity is ambiguously conceived and loosely applied, and mergers, fusions, and crossings with neighboring concepts are unavoidable and perplexing.

To restate my thesis: mathematics is the only academic discipline in which the conception of continuity can be called upon to give a rigorous account of itself, and in which it is being bridled, mastered, and made "rationally" operative.

6. DISCONTINUITY VERSUS CONTINUITY

In virtually all areas of knowledge, Western intellection since 1800 has been active against the background of a multifaceted contrariety between Continuity and Discontinuity, with the nineteenth century tending, in varying

degrees, to favor continuity over discontinuity, and the twentieth century tending toward neutrality. For mathematics I have sketched the course of the contest in a previous essay in these *Studies*;[29] for physics the contrariety will be accounted for in the second half of Part II; in the present section we will cast brief looks, really brief ones, into other parts of the landscape of knowledge.

In the social sciences and humanities the preference for continuity amounted to a veritable discovery of continuity. This was closely allied to a discovery of the version of time in the course of which developments evolve continuously and in which "everything there is has a history," as will be substantiated in the next section. But even in science the bias towards continuity was unmistakable.

Since Newton and Huygens there had been a debate over whether light is corpuscular (discrete) or undulatory (continuous). In the very beginning of the nineteenth century, Thomas Young, for whatever objective reason, decreed it to be continuous (only), and so it remained virtually till 1905, the year of a crucial paper by Einstein. Similarly, in electromagnetism, "field" theories tried to smother "particle" (that is, electron) theories out of existence for the major part of the century.

Chemistry, for all its devotion to atoms and molecules, accepted the fiction of thermodynamics, that for many "macroscopic" statements, a continuous distribution of masses is appropriate. The century developed the theory of mechanics of continuous media in various states of aggregation, and in standard mathematical paradigms mechanical matter was not only distributed continuously, but even had a finite density point-by-point. Not only was the true atomistic composition of matter ignored, but Lord Kelvin even tried to envisage single atoms in the form of continuously spread-out hydrodynamical vortices of a kind conceived by Helmholtz. The resulting "vortex-atoms" turned out to be something of an embarrassment, and they have virtually been banished from present-day textbooks. Even historical surveys by professional physicists mention them only reluctantly. But there is no reason to be quite so bashful about it; that is the way the nineteenth century functioned.

Even a physicist of the stature of Helmholtz was not able to be even-handed in the debate between Discrete and Continuous. He pioneered in the discovery, for which he is justly famous, that physiologically the ear is "attuned" to receive only a discrete set of tones, but he showed a proclivity for the presumption that acoustics is a theory of waves, that is a field theory, without bestowing on the tone levels the same theoretical importance.

In the geology and biology of the nineteenth century, the doctrine of (historical) evolution not only asserted that various states of development were following upon each other in a chronological succession, but also that the entire process was, and has been, a continuous one. The Continuity of geology and biology is hard to define; it has many facets and connotations, and it goes under various names. It is frequently called "uniformity," and the affirmation of it is the presumption of "uniformitarianism." The notion of uniformitarianism is

perplexingly difficult to define, or to apply, or both. Also, sometimes, but only sometimes, it is meant to be the antithesis to "catastrophism," but the descriptions of uniformitarianism do not necessarily suggest this opposition. It is even difficult to make out, unequivocally, whether the requirement of uniformitarianism is an internal part of the doctrine of organic evolution, that is, inseparable from "organicity,"[30] or something externally superimposed on it. In spite of all such difficulties, of which the nineteenth century was well aware, uniformitarianism won out, and the twentieth century is doggedly holding on to it. As I stated in the introduction, Immanuel Velikovsky, a very knowledgeable outsider, capitalized on these difficulties in his best-seller *Worlds in Collision*. The professionals were enraged; they have not yet forgiven him for bringing the problem so crudely into the open, and apparently do not intend to.

In social science, a deep-seated presumption of continuity, from which the nineteenth century never quite emancipated itself, was the doctrine of Francis Bacon, from the early seventeenth century, that all science advances gradually and unerringly from observation to experimentation to theoretization, and that there are ways in science of deciding between right and wrong in such a manner that an experimenting or observing scientist may collect his facts indubitably "objectively" before forming a theoretical opinion of their meaning. The twentieth century has been reacting quite militantly to this doctrine. Alexandre Koyré, for instance, opposed it almost to a fault.

The presumption of continuity was, and is, closely linked to a presumption of inevitable progress. R. G. Collingwood quotes the following absurdity from an 1880 book, *The Nineteenth Century—A History*, by a certain Robert Mackenzie:

> Human history is a record of progress—a record of accumulating knowledge and increasing wisdom, of continual advancement from a lower to a higher platform of intelligence and well-being. Each generation passes on to the next the treasures which it inherited, beneficially modified by its own experience, enlarged by the fruits of all the victories which itself has gained. The rate of this progress . . . is irregular and even fitful . . . but the stagnation is only apparent. . . . The nineteenth century has witnessed progress rapid beyond all precedent, for it has witnessed the overthrow of the barriers which prevented progress. . . . Despotism thwarts and frustrates the forces by which providence has provided for the progress of man; liberty secures for these forces their natural scope and exercise. . . . The growth of man's well-being, rescued from the mischievous tampering of self-willed princes, is left now to the beneficient regulation of great providential laws.[31]

A subtler form of continuity, which I have termed "continuism,"[32] assumes that any event of today is indeed a reaction to an event that must have taken place yesterday, but that the reaction may also be a negative one. Today's event may concur with yesterday's event and carry it forward, or it may disagree with it, and oppose it with something different. Continuism can be tedious if overdone or practiced lopsidedly. This applies to some extent to the work of the eminent historian of science Pierre Duhem in the waning nineteenth century. He was quite prolific, and even after he died in 1916 at

the age of 55, his wife published five more volumes of his *Système du monde*. He was mainly a medievalist participating in the Great Rehabilitation of the Middle Ages that had been vigorously inaugurated by the nineteenth century and that has become a large-scale academic industry in the twentieth century. As I said before, Duhem

> forges what seems to be an unbroken chain of human links, from Thales to Galileo, clear across the entire Middle Ages, without omitting a single decade, or even a single year of them. He does not naively whiten out all the darknesses of the Middle Ages; but to Duhem they only indicate a certain lowering of the level of intellectuality, and not a chasmal rupture in the substance of the flooring.[33]

Duhem's intellectual commitment to continuism barred him from carrying a historical accounting of events in the Middle Ages beyond the axis from Copernicus to Kepler and Galileo. As I have been maintaining in previous essays, the eruption of Analysis in the era of Kepler constituted a large-scale discontinuity and a great divide in the unfolding of mathematics, with consequences in the various areas of knowledge, scientific and other. No continuist narration of actions and reactions can account for it. Even in the circumscribed field of Italian Renaissance philosophy there was a sudden change of direction in the middle of the sixteenth century that cannot be explained.[34]

It is a truism that the Greek historian Herodotus was rather episodic in his presentation of political developments, whereas his successor Thucydides was powerfully continuist (in a good sense) in linking cause and effect in the arena of politics. Also Herodotus was rather expansive in his geographical, social, and related asides, whereas Thucydides was almost single-mindedly intent on unfolding his political narration. In view of this, the outgoing nineteenth century tended condescendingly to reduce Herodotus to the standing of a mere story-teller, with the unconcealed suspicion that most of his stories are only fables anyway; some bold historians might even have liked to read Herodotus out of the guild of historians because of his many asides, and to enthrone Thucydides as the Father of History instead. But in the twentieth century archeology has been triumphantly vindicating the fables of Herodotus; and the linking up of geographic, economic, and social circumstances with political developments has become a new trend.

The nineteenth century exegete of ancient literary texts was prone—even at his best—to "emend," "rearrange," or "reinterpret" the statements of the texts, in order to arrive at more "continuous" and more "natural," and thus more probable, courses of developments than those offered by the texts as they are. Frequently the twentieth century finds good causes for rejecting or at least modifying the well-meant removal of such discontinuities.

For instance, the book *Leviticus* of the Old Testament is a large collection of elaborate priestly ordinances, alien to our sensibility, composed in a highly formalized priestly lingo, which, as everybody agrees, was formed rather late,

about the time, say, of Ezekiel, the last of the great prophets. But *Leviticus* also insists that these ordinances were handed down to Moses quite early in the history of Israel, at the Sinaitic revelation. Enlightened scholars of the nineteenth century were inclined to take the reference to Moses very lightly and to conclude that not only the language but also the substance of the so-called Priestly Code was a late construction of post-Exilic times. But in the twentieth century William Foxwell Albright, an eminent American student of the Old Testament, has devoted many studies to the proposition that the substance of the Priestly Code is indeed as ancient as the Bible maintains, going back to early stages of the communal organization of the tribes of Israel.[35]

Finally, I have to dwell briefly on the fact that the nineteenth century was also a century that proposed the most rigid scientific determinism ever claimed. It is the statement of Laplace that any person possessing complete knowledge of the state of the universe at any one given moment would be able to predict the state of the universe for all times to come.[36] There is nothing more intolerant of discontinuities than this approach; and we will find in Part II that the spirit of this intolerance was still operative in Einstein's rejection of the Bohr-Born-Heisenberg world-picture of twentieth century physics.

May I state that there was an equally intolerant *social* determinism and that it was most eloquently expressed in the tenets of Karl Marx and Marxism. However revolutionary Karl Marx's expectations may have been, according to his doctrine the revolution between the classes was nevertheless historically inevitable, and the outcome was firmly predetermined. Dialectical Materialism is a fundamentally historical conception of society and even of nature. "According to this conception," said Engels towards the end of the nineteenth century, "Socialism was no longer an accidental discovery of this or that ingenious brain, but the necessary outcome of the struggle between historically developed classes."[37] This belief in social determinism did not win out without a struggle. An opposite to it, namely social *in*determinism, was embodied in Proudhon's Anarchism, and Marx had to strain all his intellectual resources to combat it.[38]

7. EVERYTHING HAS A HISTORY

The nineteenth century hardly initiated the writing of history of or in any academic field, but it intensified it to an unprecedented degree in every field.

In mathematics, in the latter half of the nineteenth century Moritz Cantor wrote a history that remains fundamental. In 1840, M. Chasles wrote a history of geometry; I. Todhunter wrote first a history of probability (1865), then a history of *Mathematical Theories of Attraction and Figure of Earth from Newton to Laplace* (1873), and then a history of the *Theory of Elasticity from Galileo to the Present* (1893).

Astronomy is, next to mathematics, the oldest "exact" science there is, yet histories of it had been very rare and sparse. As if to make up for this, the nineteenth century produced a spate of them.

At the beginning of the century, J. B. Delambre wrote an indispensable history of astronomy in six volumes (1817-1827). About the same time, P. S. Laplace wrote a somewhat popular *Précis de l'Historie de l'astronomie* (1821), and even before that J. S. Bailly composed an even more popular one in several volumes (1775-1782).

In medicine, in contrast to astronomy, a notable historical work had already been done in 1696 by the Swiss physician Daniel Leclerc. But a true beginning was made only around 1800 with a multivolume work by Kurt Polykarp Sprengel; of this work the twentieth-century historian of medicine Fielding H. Garrison said that it "has been the great source book for facts and footnotes for all subsequent investigators." In 1790 a journal in the history of medicine was begun under the title *Archiv fuer die Geschichte der Arzneykunde.*

A large-scale history of physics was compiled in 1860 by F. Rosenberger. It had been preceded in 1838 by a history of optics by S. Wilde, and even much earlier by histories of electricity (1770) and of light (1771) by Joseph Priestley. In chemistry two fundamental works by H. Kopp and by F. Hoefer were published in the 1840s. In geology, a systematic full-scale history came only in 1899, and it was the *Geschichte der Geologie* by K. A. Zittel. That such a book should appear relatively late is surprising, seeing that geology in the nineteenth century had an intrinsic historical orientation from the outset.

Special mention should be made of two works that, in their separate ways, were most influential. The many-sided Cambridge don William Whewell produced in 1837 a *History of the Inductive Sciences*, which in a sense created the genre of "History of Science" in our present-day sense. The second work appeared in the last decades of the Victorian era, a "critical" history of mechanics by Ernst Mach, which greatly enhanced the role of mechanics within physics as a whole. Above all, this was Einstein's lifelong *vade-mecum* in matters philosophical. His self-indoctrination with the philosophy of Mach may have created the intellectual barrier that kept Einstein from entering the twentieth century of physics during the long second half of his career.

In the history of law, there appeared relatively early in the century two compendious works from Germany, one on German law by Karl Friedrich Eichhorn (*Deutsche Staats- und Rechtsgeschichte*, 4 volumes, 1808-1823), and another on Roman law, by Friedrich Karl von Savigny (*Geschichte des Römischen Rechts im Mittelalter*, 6 volumes, 1815-1831). They were part of the rehabilitation of the Middle Ages mentioned in the preceding section, and of a growing estimation, and sometimes overestimation, of medieval achievements. For many scholars, and even generations of scholars, to vindicate the Middle Ages became, and continues to be, a consummation devoutly to be

wished. Many books on aspects of life in the Middle Ages began to sound like by-lines of contemporary American correspondents abroad. Many books on popular themes can be written in this way, the story of Abélard and Héloïse being probably the most popular.

Present-day theories of automation, communication, and information involve abstract situations of linguistics, and such situations began to be shaped in the nineteenth century within its evolutionary outlooks. For instance, the introductory paragraph of a leading work on the *The Discovery of Language* runs thus:

> Until the close of the eighteenth century, European linguistic science had advanced but little beyond the knowledge of linguistics achieved by the Greeks and Romans. It is true that little by little some of the elements had appeared which were necessary for development beyond the limitations and errors of the ancients, but as yet they had no influence. The soil was prepared, but it was not until the nineteenth century that growth was destined to spring from it.[39]

This statement exaggerates in one respect. Another book on linguistics, a recent one, adduces an overwhelming amount of evidence for successful linguistic studies even before the beginning of the nineteenth century.[40] Thus, an impressive achievement was the 1770 publication by J. Sajnovics of a *Proof that the Languages of the Hungarians and the Lapps Are One and the Same*, followed in 1799 by a study of S. Gyarmathi—apparently a much more systematic one—which deals with "the historical kinship of Hungarian and Finnish."[41] Already Leibniz, in the *first* half of the eighteenth century, "was one of the first to posit historical relations between Finnish and Hungarian."[42]

What definitely belong to the nineteenth century are the highly spectacular feats of deciphering hieroglyphs and cuneiform writing. And if the nineteenth century did not succeed in reading Etruscan inscriptions, then it need not be ashamed of itself, because the twentieth century has not much advanced in this task either.

Books on the history of linguistics hardly mention feats that astound the impressionable layman. What they count mostly as the truly innovatory and unprecedented achievement of the nineteenth century is the emergence and systematic pursuit of *comparative* grammar, which officially began in the late eighteenth century with a famous statement by Sir William Jones, a British judge in India. Jones had studied a wide variety of languages, and in 1786 he delivered his famous *Third Anniversary Discourse*, which reads in part:

> The Sanskrit language, whatever be its antiquity, is of a wonderful structure; more perfect than the Greek, more copious than the Latin, and more exquisitely refined than either, yet bearing to both of them a stronger affinity, both in the roots of verbs and in the forms of grammar, than could possibly have been produced by accident; so strong indeed, that no philologer could examine them all three, without believing them to have sprung from some common source, which, perhaps, no longer exists. There is a similar reason, though not quite so forcible, for supposing that both the Gothic and the Celtic, though blended with a very different idiom, had the same origin with the Sanskrit; and the Old Persian might be added to the same family.[43]

The expression "comparative grammar" was coined in 1808 in Friedrich von Schlegel's *Über die Sprache und Weisheit der Inder* (On the Language and Wisdom of the Hindus), with the following send-off: "Comparative grammar will give us entirely new information on the genealogy of languages, in exactly the same way in which comparative anatomy has thrown light upon natural history."[44] The ensuing findings about genealogical proximities and distances between languages must have been thrilling to contemporaries, even if the twentieth century has become blasé about such statements. But even today, word-compounds like Indo-European and Finno-Ugric speak volumes of history; and even today it can be astonishing to hear that Old Norse and Old Albanian are much more consanguineous than, say, Hebrew and Greek, even if central passages in the Gospels bear tell-tale marks of being translations from Hebrew-Aramaic originals.

In very few cases of historically oriented studies has there been such a difference in knowledge between A.D. 1800 and A.D. 1900 as in the understanding of the rise, spread, and distribution of spoken and written languages, especially the written. The subsequent developments in the twentieth century seem to concentrate on *spoken* language and languages, as against the *written* ones. This accords with the fact that until the nineteenth century the study of linguistics was preponderantly historical. In the twentieth century it is historical and analytical in equal measure.

Next, the pedagogy (this is a formal name for education) of today is laced with psychology. This link was forged systematically in the early decades of the nineteenth century by the all-purpose philosopher Johann Friedrich Herbart, even before psychology was an academic field in its own right, independent of philosophy. Herbart was not only also a psychologist, as most philosophers at the time still were automatically, but he was also a lifelong devotee of pedagogy, which he included in his psychology, thus making pedagogy into a kind of applied psychology. He was successful in this although the psychology current at his time was not sufficiently articulated to be adequate for the purpose.[45] It was Herbart who became the founder of "scientific" pedagogy—albeit by turning it into an applied psychology in a sense—and not the celebrated Pestalozzi, his forerunner, for whom the theoretical basis of education consisted of the maxim that "Love in the classroom conquers all." A recent history of education fondly remembers Herbart thus:

> The great advance made by Herbart—and its importance can hardly be exaggerated—is that he based his educational views on a new and fully worked out psychology. He is therefore the forerunner of the whole subsequent school of educational reformers who had held that their first requirement was an independent study of the workings of the human

> mind. . . . For the first time an educational prophet saw the necessity of deriving his theories from a coherent psychology.[46]

In psychology proper, Herbart jumped ahead of the twentieth century and conceived of "thresholds of consciousness," "inhibitions," and "repressions." His inhibitions and repressions referred only to ideas and not yet to fears and desires; even so, his adumbrations were enough to secure for him several mentions in the standard biography of Sigmund Freud.[47] By searching diligently enough, one could probably find that any proposition by Herbart had been conceived before him, by Kant, Leibniz, Locke, Aquinas, Aristotle, and so forth. But this finding would be of no consequence: every one of Freud's major maxims had once been somebody's aphorism long before Freud. Also, Herbart's notions were sufficiently free from metaphysical encumbrances to be noticed by Freud, whereas previous ideas were very much a part of the philosophical framework.

Finally, the everyday vocabulary of social science—though not all of it—is also a creation of the nineteenth century.

Aristotle even pioneered in saying that man is a "political animal." But the Greeks did not understand our concept of "state," only something like "the totality of the citizenry." The Greeks could not have made the pronouncement that "the state will wither away." Our concept of state began with Machiavelli.

The Greeks did not have our notion of a "constitution," only of something in the nature of "the totality of laws." They could not have said that something is "unconstitutional," only that it is unlawful or illegal. Nor did they have our conception of "international law." In the Roman Empire, conceptions like "cosmopolitanism" and "international law" would have referred to the Roman Empire in its total extent, and perhaps also to its spheres of influence, but not to something truly worldwide. Such conceptions emerged only in the seventeenth and eighteenth century.

Next, the nineteenth century created the conception of socialism. Although the term occurs in print as early as 1803, it took several decades before it became knowingly associated with reforms of social order and assertions of human rights.[48] Soon afterwards the term *anarchy* was consciously created by Proudhon, around 1840, and anarchism was apparently from the first intended to be opposed to socialism. Communism, however, not only as a principle of joint property, but even as a way of life, was already fully known to the Greeks. Plato advocated it in his *Republic*, but with a very pronounced authoritarian slant; nothing corresponding to our present-day "leftish" notion of civil rights was involved.

But the slogan of "the exploitation of man by man" was coined in the early nineteenth century; it was created, well before Marx, by Saint-Armand Bazard (1791-1832).[49] Marx institutionalized the term and concept of Alienation; but it had been used, earlier in the nineteenth century, by Hegel.

"*Sociologie*" was coined in 1839 by Comte. It was apparently intended to replace in Comte's usage the earlier expression "*physique sociale*," which had been created by Henri de Saint-Simon (1760-1823), then used in 1835 in a book title by A. Quetelet, the creator of the "average man" (*homme moyen*), and also used by Comte himself. In English, "sociology" began to be used in book titles in the 1870s both in Great Britain and the United States. In the 1890s, Chicago University may have had the first professor of sociology so titled.

> Except for the academic field of Politics, if Sociology is not just an objective representation of social facts, but a program of prying into the meanings of social facts; if it is not just the history of ethical systems, of cultic practices, of mythological beliefs, etc., but an attempt and effort to find systematic techniques for interpreting ethical systems, cultic practices, mythological beliefs, etc.; then sociology has begun around and after 1800, and is one more of the really great achievements of the century.[50]

8. PESSIMISTS

The nineteenth century had pessimists and prophets of doom. So did earlier centuries. But in the nineteenth century they were radically different, a new breed.

Even before the century began, in 1792, Thomas Robert Malthus, a parson among many, warned mankind that it will starve itself out of food unless it controls the size of its population. The leading aspects and arguments of the Malthusian Principle may have been worked out by various population-economists long before Malthus.[51] But it was Malthus who caught the attention of the public, by casting a pall that refuses to dissipate. In fact, the world seems to be running out not only of food, but of natural resources altogether. Karl Marx, being a humorless optimist and eschatologist, and unrelenting when in opposition, hated Malthus, and, as was his wont in intellectual confrontations, heaped scorn on him. To Marx, the proletariat was fated to win, albeit by violence; a betterment of the world was sure to come. No Malthus would change that.

Next, in the middle of the nineteenth century, culminating in 1865, the thermodynamicist Rudolf Clausius created his second law of thermodynamics and applied it to the universe as a whole. The outcome was that the available energy of the universe is unceasingly transforming itself into uncreative uniform heat, thus leading the universe inexorably to a "heat death, in which the world shall be reduced to one vast temperature equilibrium in which nothing really new ever happens. There will be nothing left but a drab uniformity out of which we can expect only minor and insignificant local fluctuations."[52]

This heat death would take millions, even billions of years to come about. But intellectuals have been frightened by the prospect of it nonetheless. Thus

Henry Adams wrote "A letter to American Teachers of History" about it, and quite recently an economist wrote a large economic treatise on the theme of the Second Law of Thermodynamics.[53]

Clausius coined the term *entropy* by which to quantify his law. It designates a real-valued quantity measuring, in a thermodynamic process, when it is completed, the extent to which the amount of heat has increased at the expense of other available energy. Thus the entropy of the universe in its entirety is on the increase. But only for the universe in its entirety. In select parts of the universe it may on occasion decrease. Such a decrease in a part of the universe must be compensated for somewhere else by an increase at least as large. In the kinetic theory of gases, itself part of so-called statistical mechanics, heat is generated by the "irregular" motion of microscopic particles. If one interprets this irregular motion as "disorder," then the entropy measures the degree of this disorder, the higher the entropy the larger the disorder. And the second law of thermodynamics states that in the universe as a whole, the total disorder is constantly on the increase.

On the other hand,

> Living organisms represent systems that are highly "organized," that is, they display less randomness than the materials from which they are "built"; and it is therefore justifiable to say that a *decrease* in entropy is involved in their building.[54]

By what we have noted above, this decrease in entropy must be compensated for by an increase somewhere else. In fact, "the small local decrease in entropy represented in the building of the organism is coupled with a much larger increase in the entropy of the universe."[55]

A very discouraging consequence arises if one equates disorder with the "pollution" of everyday parlance. In this interpretation, the total pollution of the universe can only increase, and any attempt at clearing up an environment results in an even worse pollution in some layer outside the given environment. Thus, terrestrial nuclear waste cannot be literally disposed of. At best it can be transported into another part of the universe, with some additional pollution as "transportation compensation" arising. There is one dubious theoretical way out. Even if one admits that entropy is constituted by disorder, it is still very difficult to say what "disorder" in entropy really is.[56]

Finally, at the end of the nineteenth century, there appeared, before the end of World War I, Volume I of *The Decline of the West*, by the "prophet of doom" Oswald Spengler. Leaving aside Spengler's insistence on the cyclicity of history, but focusing on his comments on tangible phenomena, one sees that his analysis, whether retrodictive or predictive, cannot be simply ignored. His retrodictive interpretation of differences between Greek and modern mathematics is most pertinent; and before 1920 he predicted for the second half of the twentieth century the kind of civic lawlessness and social fragmentation that we are undergoing nowadays.

Malthus, Clausius, and Spengler were social or physical scientists. In between were the literary pessimists.

Between Malthus and Clausius there was Arthur Schopenhauer, a philosopher-pessimist in the manner of Heracleitus. According to him, human life not only *may* contain more misery than happiness but this *must* be so, on philosophical grounds. There is only one progress, progress towards more misery.[57]

Between Clausius and Spengler there was Lev Tolstoy with his pessimistically moralistic *Kreutzer Sonata*, and above all, Friedrich Nietzsche, a brooding philosopher of ambiguous outlooks, whom Spengler viewed as one of his two mentors (the other being Goethe).

In the twentieth century, successor pessimists to all the above were, among others, Franz Kafka, the Jean Paul Sartre of *Nausea*, and the Sigmund Freud of *Discontent in Civilization*. Also (and this will be a prime lesson in Part II), much of what can be taken for general pessimism was "sublimated" into twentieth-century physics. More about this in Part II itself.

9. THE IRRATIONAL VERSUS THE RATIONAL

After World War I, the anti-democratic forces in post-war Germany that eventually brought forth Nazism rallied intellectually under the flag of a contrariety of Irrationality versus Rationality. They did so from an overwhelming Teutonic fear of, distrust of, contempt of, and horror of what the German intelligentsia, and especially the superintelligentsia, called "rationality," and they gave way to a headlong abandonment into and passion for what they called "irrationality," with a religio-mystical flavor entirely of its own. The despised and feared and to-be-exterminated rationality was, according to the Germans, a mark of Frenchmen, Jews, Freemasons, and misguided Anglo-Saxons for whom rationality and the profit motive were inseparable.

A recent study by an expert author seems to suggest, if I interpret the author correctly, that Werner Heisenberg was compelled and impelled towards inventing his matrix mechanics in response to an all-encompassing "ecological" and cultural pressure for overcoming determinism, causality, "mechanical" rationality, etc., in favor of indeterminism, uncertainty *qua* a-causality, freedom from stifling and un-German "rationality," etc.[58] The study is extremely well documented, and for my part I can only rely on memory of my personal experiences and impressions, having lived through the period in Germany already as an adult. I do not even have any kind of diaries by which to refresh my memory. I nevertheless venture to make some observations on the intellectual climate during the so-called Weimar Period or Weimar Culture, as the setting in Germany between World War I and the ascent of Hitler has come to be known.

My first overall observation is that things were very bad, and the academic atmosphere in Germany was oppressive indeed, and growing more so. But I simply do not remember at all that mathematicians and physicists and other scientists were the choice targets of this oppressiveness, and that they acted and re-acted as such. In particular, young and aspiring mathematicians and physicists did in no way consider themselves as being worse off than students of classics, or of other humanistic pursuits, or even of German history and literature, than which there was nothing more sacred in the land. Things were bad, but not along such a scientific/humanistic line of division.

I do not mean to absolve the bearers of Weimar Culture of their very many and very stubborn sins of omission and commission. I agree with the present-day German historian Fritz Fischer in his thesis—which he stoutly defends against all critics and detractors—that the World War of 1914-1918 was brought about, almost inevitably, by the German bourgeoisie in all its layers, and foremost by its intellectuals; by uncontrollable dreams of glory of globe-spanning world domination, physically, materially, and also intellectually. And when the dreams were all shattered, most of the nation, especially the educated classes, and most especially the university crowds, were seeking for scapegoats all over the landscape, not only in political areas but also in intellectual ones. And a climate of oppressiveness was developed and sustained.

All this is true. But to cap these insights by the conclusion that these movements of intellectual obfuscation were somehow responsible for the rise and creation of the theories of quantum mechanics and of wave mechanics does not sound right to me. It simply did not happen this way.

My second general observation is that there were two very separate phenomena involving discontinuities and that they must not be conflated, as is sometimes regrettably done. Both are large-scale phenomena of Western intellectuality, both worldwide, and not necessarily of German origin, however much Weimar Germany may have cultivated them to excess. These several phenomena do overlap, and the Weimar intellectuals themselves did conflate them too. But from a historical distance of a half-century they ought to be kept apart and traced to their divers origins.

1. The first phenomenon, or movement, a most "international" one, was, and still is, a struggle to grasp the interrelations, differences, and (in-) consistencies of some seemingly related or contrasting cognitive concepts, axioms, and procedures, like causality, determinism, functional (inter-) dependencies, mathematical certainty, statistical certainty, certainty as a limit of statistical probability, etc.

This struggle may have had antecedents in antiquity and the Middle Ages, but it really began after the Renaissance with the British empiricists and was institutionalized by David Hume with his affirmation that "causality," whatever that may be, is at best "association" and nothing more "binding." Kant made one of philosophy's greatest efforts to save causality by shoring it

up with Apriorism. But hardly anybody believed that Kant's was the last word in the matter. Even the relatively secondary question, whether and to what extent causality is co-extensive with determinism, refuses to come to rest. And the widespread identification of causality and/or determinism with the "certainty" and "predictability" of a Newtonian mechanical point system was in the twentieth century almost too childish to debate, even if thundering superintellectuals of the Weimar Culture sometimes took this identification for granted, as did also, regrettably, many intellectuals of the "enlightened" West.

The "experiential" or "empirical" association of Hume leads only too naturally to such intellectual constructs as Mill's inductive logic in Britain, and pragmatism and instrumentalism in the United States; or, at least, it cannot be neatly separated from them. And even the element of "probabilism" in the great theories of statistical mechanics and physics of the nineteenth century has a certain link to it.

In sum and in short, the profession of a-causality in the broadest sense was in no wise a Teutonic institution, however much the Weimar Culture may have pushed it to extremes.

2. A rather different phenomenon, which the Germans had a greater share in creating, was the quest for "irrationality." It was more popular than the quest for a-causality, even though only its academic formulations by various Germans have become generally known.

Of course in the heady outpouring, verbal or written, of a muddle-headed or mischievous German on the (pseudo-) intellectual war-path, the two phenomena, that is, irrationality and a-causality, frequently merged, but in a serious study today they ought to be kept apart. Furthermore, when the outpouring came in a solemn address, or an article-to-such-a-purpose by a German professor, then one still must consider the difference between delivering oneself of such a declaration or declarations, and actually applying the lesson from it in one's day-by-day routine work in the lab or classroom, or behind a desk with a pile of books on it. The latter application occurred much more rarely than so-called documentations might suggest.

That irrationality is really something very different from a-causality in its main manifestations can be seen from the following statement about it by an expert:

> Future historians will, I believe, recognize in this preoccupation with the surd element the governing impulse of our time, the *daimon* or Zeitgeist which in different guises has haunted minds as various as Nietzsche, Bergson, Heidegger in philosophy; Jung in psychology; Sorel, Pareto, Spengler in political theory; Yeats, Lawrence, Joyce, Kafka, Sartre in literature; Picasso and the surrealists in painting.

The expert is E. R. Dodds, a prominent British classicist, author of the book *The Greeks and the Irrational*; the aphorism above is a footnote to his article

"Plato and the Irrational," which is Chapter VII in his book *The Ancient Concept of Progress and Other Essays on Greek Literature and Beliefs* (1973). This author's own work on irrationality deals with a very special aspect of it, namely with its manifestations in Greek religion, but the author seems very knowledgeable about the conception in general.

It is noteworthy that in Dodds's list the Germans do not even predominate. The only true Germans on it are Heidegger, Nietzsche, and Spengler, because Jung is culturally Swiss, and this is not the same as being German. And among non-Germans Bergson, I think, was a much more pronounced and influential irrationalist than is sometimes conceded. I remember that around the time when Hitler was close to coming to power, some "Nazi intellectuals" were disappointed that Bergson was a Jew, because they would have liked to put him into their Living Hall of Fame (he lived till 1938).[59]

3. I also question the widespread view that anybody in the Weimar period who quoted something meaningful from Spengler with approval was necessarily an irrationalist like Spengler. This does not follow. It is wrong to posit that everybody during the Weimar Culture who was fascinated by Spengler and was carried away into quoting him was necessarily a grave-digger of this culture. In this sense I must put in a kind word for Ernst Troeltsch (1863-1923), who is sometimes mistaken for an unmitigated irrationalist. Troeltsch is the author of the monumental work in two volumes *The Social Teaching of the Christian Churches*; of the large historiographic work *Der Historismus und Seine Probleme* (Tübingen, 1922); of the still very readable article on the German Enlightenment, "Die Aufklärung," in *Real-Encyclopädie für protestantische Theologie und Kirche*, Third Edition, vol. II (1897), pp. 225-241; and of some articles to the effect that the outbreak of the (First) World War was due to some kind of "breakdown of communications," as one would put it today, rather than to diabolic intent on either side. During my student days at the University of Berlin (I enrolled in the autumn of 1918) Troeltsch used to give, every term, I think, a lecture two hours a week (Saturdays, 10-12, with an intermission) which bore the title "Introduction to Philosophy" and was in fact an introduction to his current interests in philosophy. During one of the lecture hours he simply presented, in an agitated manner, a "book review" of volume I of Spengler. As I remember the book review, it was not at all an extolling of irrationality or a-causality, but simply the exposition of a new approach to the "morphology of world history," as Spengler himself had called the book originally. (As I heard it at the time, it was the publisher who suggested the title *Decline* [Untergang] *of the West*, simply as an advertising gimmick.) It soon became mandatory to discuss Spengler endlessly. It was just a fashion, and as a fashion it was not nearly so widespread as had been twenty years before in Paris the compulsion to discuss Bergson.

Also it must be taken into account that Troeltsch died relatively soon after the outburst of the Spengler mania, and perhaps had he lived longer, he might

have had reasons and opportunities for reconsidering his stand on various implications of Spenglerism.

4. One must not make too much of the fact that during the Weimar period mathematics and physics were taken to task for being intellectually too presumptuous and too demanding of attention, and that some mathematicians cringingly admitted guilt. To this charge I can only say that during the Weimar period mathematics stood generally in very high regard, and that this kind of ambivalence of attitude towards mathematics is as old as academic mathematics itself, the word *academic* to be taken literally (that is, since the times of the Platonic Academy itself).

In the early nineteenth century, the German *Naturphilosophen* (nature-philosophers) had a deep intellectual suspicion of mathematics. Yet, from around 1800 until today every great university of the West has had a great mathematics department. In the seventeenth century Francis Bacon, a paragon of modernism, was contemptuous of mathematics. But it was a great century in mathematics nevertheless, and hardly any of Bacon's general followers echoed his attitude towards mathematics. In the thirteenth century Roger Bacon was a noisy advocate of mathematics, and he was so noisy about it that there must have been many others who were indifferent to it or worse. Around 1200, Fibonacci made such a splash with his *Liber abaci* that at the court of Frederick the Second in Sicily he was dined and wined, figuratively speaking. On the other hand, the important work of Oresme and others from the fourteenth century was all but forgotten after 1600, and was only re-discovered in the nineteenth century as a part of the Great Rehabilitation of the Middle Ages then commencing. Ambivalence towards mathematics is as old as mathematics itself.

5. Finally we come to the suggestion that Heisenberg's matrix mechanics, with the consequent uncertainty-relation, and thus the entire physics since, came about by a soul-anguished desire to respond to the (allegedly) all-pervading quests for a-causality, indeterminism, irrationality, etc. This suggestion is untenable.

The matrix-mechanics was a genuine development in physics-for-physics' sake, and it was spawned not in Germany but in Copenhagen. Only a part of the German sense of exhilaration over this achievement was pride in Heisenberg's being a German. And several among the leading co-architects of the new theory were as un-irrational as they could possibly be; nobody who ever met Dirac or Fermi could conceivably suspect them of allowing themselves to be tools in a drive towards legitimizing irrationality of any kind. Schrödinger, creator of the theory of wave mechanics, although an Austrian, may have had some tendencies towards Teutonic irrationality; but he acknowledged a measure of indebtedness to Louis de Broglie, who not only is as rational as only a certain caste of Frenchmen can be, but also was a staunch ally of

Einstein in his battle to eliminate any kind of Heisenberg uncertainty or indeterminacy altogether.

It is noteworthy that Russian textbooks on quantum mechanics, especially on the more advanced quantum *field* theory, speak not of a Heisenberg "uncertainty"-relation but simply of a "Heisenberg Law," which reigns in the "microscopic" realm of elementary particles, and they seem to have no difficulties at all. That is, they seem to have no difficulties in harmonizing this with the "macroscopic" Marx-Engels law to the effect that in the realm of economics and class relations everything is deterministic, and is in fact determined by dialectical materialism.

An undergraduate today is not disconcerted by the "Heisenberg Law." He is no more disconcerted by the statement that p and q cannot be observed with a joint precision more than $\frac{h}{2\pi}$ than by the statement that light of frequency ν travels in units of energy $h\nu$. Both these statements assert the existence, or rather presence, of certain "discontinuities" in physical nature, and our *Zeitgeist* is simply willing to accept them. It would be carrying things too far to assert that it was the Weimar Culture that mightily promoted this universal movement that distinguishes the twentieth century from the preceding nineteenth century, and that the bearers of the Weimar Culture brought this about from "sinister" motives too.

10. GREATNESS OF THE NINETEENTH CENTURY

I will list some noteworthy achievements from the span A.D. 1850-1870. It is a ribbon across the center of the extended nineteenth century 1800-1920, of the same width as the interval between the two World Wars in the twentieth century.

1850s Gustav R. Kirchhoff, with the partial cooperation of Robert M. Bunsen, founds spectroscopy

1850s Theodor Mommsen, *Roman History*

1851 Herman Melville, *Moby Dick*

1854 Bernhard Riemann's lectures on (Riemannian) geometry, published posthumously 1868

1857 Gustave Flaubert, *Madame Bovary*

1859 Charles Darwin, *The Origin of Species*

1860 Jacob Burckhardt, *The Civilization of the Renaissance in Italy*

1860 Louis Pasteur becomes "Father of Bacteriology"

1860 Bernhard Riemann initiates the mathematical theory of (dreaded) shockwaves

1860 Gustav T. Fechner and Ernst H. Weber create the Weber-Fechner Law (Response = logarithm of stimulus)

1862 Victor Hugo, *Les Miserables*

1862 Abraham Lincoln, *Emancipation Proclamation*

1864 James Clerk Maxwell, theory of electro-magnetic radiation

1864 Angelo Secchi begins spectroscopic analysis of sun and stars

1865 Rudolf J. E. Clausius, entropy and its Law

1865 Friedrich J. Kekulé, ring structure of organic compounds (benzene ring)

1865 Joseph Lister introduces antiseptic surgery

1865 Gregor Mendel, Law of Inheritance

1865-1869 Lev Tolstoy, *War and Peace*

1865-1870 Paul Cézanne begins to exhibit

1866 Feodor Dostoevski, *Crime and Punishment*

1868 Karl Marx, *Das Kapital*

1868 William Huggins uses red-shift to prove that Sirius is moving away from the sun

1869 Dimitri Mendeleev, *Periodic Table*

1870 Heinrich von Stephan conceives the Universal Postal Union, the first permanent international organization

[I wish I could include Verdi's *Aida* (1871) and, above all, Bizet's *Carmen* (1875).]

NOTES

1. Gilbert Chinard, "Progress and Perfectibility in Samuel Miller's Intellectual History," *Studies in Intellectual History* (Baltimore, 1953).

2. G. D. H. Cole, *A History of Socialist Thought* (London, 1954), vol. II.

3. N. Lukiesh, *Artificial Light, its Influence upon Civilization* (New York, 1920).

4. C. C. Gillispie, *Genesis and Geology* (Cambridge, Mass., 1951), pp. 42-43.

5. Francis C. Haber, *The Age of the World, Moses to Darwin* (Baltimore, 1959), p. 118.

6. See appropriate passages in "The Age of the Earth," *Bulletin of the National Research Council* **80** (June 1931); see also Lawrence Badash, *Rutherford and Boltwood, Letters on Radioactivity* (New Haven, 1969), p. 17.

7. In 1871, in a lecture given twice, Helmholtz gave 22 million years for the past of the earth, and 17 million for the future ("On the origin of the Planetary System," *Popular Lectures on Scientific Subjects*, Second Series, p. 182). His main argument had already been stated in 1854, but without specific figures ("On the interaction of natural forces," *Popular Lectures on Scientific Subjects* [London, 1873], pp. 153-196).

8. J. D. North, *The Measure of the Universe* (Oxford, 1965), p. 8.

9. There was one very isolated occurrence in the middle of the eighteenth century. See Edmund Whittaker, *A History of the Theories of Aether and Electricity*, vol. I, *The Classical Theories* (Harper Torchbook, 1960), p. 367.

10. Ibid.

11. Ibid., pp. 99-100 and 367.

12. Ibid., p. 371.

13. See the article on Huggins in *Dictionary of Scientific Biography*, C. C. Gillispie, editor, vol. 6, p. 592.

14. Isaac Asimov, *The Universe, From Flat Earth to Quasar* (New York, 1966), p. 68.

15. Ibid.

16. Most recently in "The Emergence of Analysis in the Renaissance and After," *Rice University Studies* **64**, nos. 2 & 3 (Spring-Summer 1978): 25ff.

17. Salomon Bochner, "Mathematical Background Space in Astronomy and Cosmology," *Vistas in Astronomy* **19** (1975): 133-161.

18. In "Emergence of Analysis," cited in note 16.

19. Bochner, *The Role of Mathematics in the Rise of Science* (Princeton, 1966), pp. 191-192; see also, "Mathematical Background Space" (cited in note 17), p. 160, top.

20. Robert L. Delevoy, *Directions of the 20th Century Arts*, translated by Stuart Gilbert (Geneva, 1965).

21. "Emergence of Analysis," p. 36.

22. Delevoy (see note 20), p. 74 (modified).

23. Kurt Badt, *The Art of Cézanne* (Berkeley, Calif., 1965), p. 161.

24. To the above see my article "Space" in *Dictionary of the History of Ideas* (1973), vol. 4, pp. 295-307, especially p. 305.

25. Andrew G. van Melsen, *From Atomos to Atom* (Pittsburgh, 1952).

26. On this subject and following, see my article, "Continuity and Discontinuity in Nature and Knowledge," *Dictionary of the History of Ideas* (New York, 1973), vol. I, pp. 492ff.

27. Probably the most authoritative account is in H. A. Wolfson, *The Philosophy of the Kalam* (Cambridge, Mass., 1976); but see also Majid Fakhry, *Islamic Occasionalism and its Critique of Averroës and Aquinas* (London and New York, 1958).

28. See "Continuity and Discontinuity"; and "The Emergence of Analysis."

29. "Singularities and Discontinuities," *Rice University Studies* **59**, no. 2 (1973): 21-40.

30. The most penetrating study of this problem known to me is François Jacob, *The Logic of Life, A History of Heredity*, translated by B. C. Spillman (Pantheon Books, 1973).

31. R. G. Collingwood, *The Idea of History* (New York, 1956), p. 145.

32. *The Role of Mathematics*, cited in note 19; see index under "continuism."

33. Ibid., p. 117.

34. "Mathematical Background Space," and "Emergence of Analysis."

35. William Foxwell Albright, *From the Stone Age to Christianity* (Anchor Book, 1957).

36. Alfred Stern, *Philosophy of History and the Problem of Values* (The Hague, 1962), p. 15.

37. Ibid.

38. Leonard I. Krimerman and Lewis Perry, editors, *Patterns of Anarchy* (Garden City, N.Y., 1966); David E. Apter and James Joll, editors, *Anarchism Today* (London, 1971).

39. Holger Pederson, *The Discovery of Language* (Cambridge, Mass., 1931).

40. R. H. Robins, *A Short History of Linguistics* (Bloomington, Indiana, 1967).

41. Ibid., p. 170.

42. Ibid., p. 168.

43. Ibid., p. 134; Thomas H. Sebeok, ed., *Portraits of Linguists: A Biographical Source Book in the History of Western Linguistics, 1746-1963* (Bloomington and London, 1966), vol. I, p. 5.

44. Pederson, *Discovery*, p. 19.

45. Luella Cole, *A History of Education, Socrates to Montessori* (New York, 1950), p. 495.

46. A. D. C. Peterson, *A Hundred Years of Education* (London, 1952), p. 78.

47. Ernst Jones, *The Life and Work of Sigmund Freud* (New York, 1953), vol. I, pp. 281, 366, and 372-376.

48. G. D. H. Cole, *A History of Socialist Thought* (New York, 1953), vol. I, pp. 1-2.

49. Heinz Maus, *A Short History of Sociology* (New York, 1956), p. 11.

50. Albion W. Small, *Origins of Sociology* (Chicago, 1924, reprinted New York, 1967), p. 37.

51. Joseph A. Schumpeter, *History of Economic Analysis* (New York, 1954), pp. 254-255.

52. Charles Lincoln Van Doren, *The Idea of Progress* (New York, 1967), p. 155.

53. Nicholas Georgescu-Roegen, *The Entropy and the Economic Process* (Cambridge, Mass., 1971).

54. Harold F. Blum, *Time's Arrow and Evolution*, second edition (Princeton, 1955), p. 94.

55. Ibid.

56. P. W. Bridgman, *The Nature of Thermodynamics* (Cambridge, Mass., 1940), pp. 166ff.

57. Frederick Copleston, *Arthur Schopenhauer: Philosopher of Pessimism* (London, 1947), p. 28.

58. Paul Forman, "Weimar Culture, Causality and Quantum Theory, 1918-1927. Adaptation of German Physicists and Mathematicians to a Hostile Intellectual Environment," *Historical Studies in the Physical Sciences*, ed. by R. McCormmach (Philadelphia, 1971), vol. 3, pp. 1-116.

59. Henri Bergson taught that in addition to "rational" time that can be measured by the clock there is an "irrational" duration that cannot be quantified.

PART II

A LECTURE ABOUT EINSTEIN

Albert Einstein[1] was universally lionized during his lifetime, perhaps more so than any scientist in modern times.

It is hard to describe the storm that broke loose around him in Berlin, where I also lived, after World War I, in late 1919, when his theory of relativity began to be talked about, everywhere, anywhere, anytime, in academic halls and in beer halls. The waves of the storm spread quickly all over the world. Newspapers talked about him and reported on his movements for years on end.

Nothing detracted from his standing. In Berlin it was taken for granted that his mannerisms were all publicity devices. His wearing long hair was jocularly ascribed to a competition against the similarly coiffed playwright Gerhard Hauptmann, 1912 Nobel Prize winner for plays on social themes. Around 1926 an older mathematician who had observed him over many years remarked to me that Einstein was his own best and most watchful publicity agent. But none of this was intended to impugn his greatness, nor did it affect the adulation of him.

In this country the *New York Times* began to report on him in 1920.

In 1926, Mrs. Josepha Wheeler, daughter of the eminent American astronomer Simon Newcomb, solicited from Einstein, then in Berlin, a statement about her father's work to be deposited with his papers in the Library of Congress. Einstein did respond with a statement, praising Newcomb's work towards explaining deviations of planetary orbits from their elliptical Keplerian paths due to gravitational interference from other planets.[2]

In 1929 Einstein wrote a paper on Unified Field Theory, one of several attempts, none of enduring outcome, to force all of physics into the mathematico-physical mold of his theory of gravitation. As I remember it, the American newsmen in Berlin burned up the transatlantic cables transmitting the entire text of the paper to the United States, intricate formulas and all. This account is from my memory. But it is a documented fact that a trustee of Wesleyan University purchased the manuscript directly for deposit at the Olin Library at Wesleyan.

Abraham Flexner, the first director of the Institute for Advanced Study in Princeton, liked to regale young people with stories of his exploits. I was sometimes present, being a member not of his Institute but of Princeton University. Sometime in 1934 he told us how he persuaded the Bamberger Family of Newark, New Jersey, to come across with a donation to found the Institute. It was in 1931, and nobody was willing to make money commitments. Finally the patriarch of the clan blurted out: give us Einstein and you can have your Institute.

And I do remember that probably late in 1931, newspapers in Germany reported that henceforth Einstein would be dividing his time between his position in Berlin and a lush academic sinecure in Princeton, U.S.A.

When late in 1933 he was sailing from Europe for permanent residence here, at the pilot stop in New York harbor two trustees of the Institute took him off the steamer in a tugboat for quick processing in the port.

Finally, during World War II, at a war bond rally in Kansas in 1944, a manuscript copy of Einstein's 1905 paper on special relativity was sold for six million dollars and deposited in the Library of Congress.

Why Einstein should have received such public attention and esteem is, I think, an intriguing problem in mass psychology. After all, Einstein did not write a treatise like Darwin's *Origin of Species*—which, as I remember it, the contemporary *New York Times* called a book in a century—or, if this be too controversial, like Newton's *Principia* (that is, *Mathematical Principles of Natural Philosophy*), the like of which has not been created before or since. For instance, the *Principia* predicted that some day a projectile would be launched with a sufficiently high velocity to make it an earth satellite. This was seriously spoken of in the eighteenth century, even though it came true only in the middle of the twentieth century. I do not think that there is anything like this in the writings of Einstein. In a splendid paper of 1916 Einstein recognized the existence of *stimulated emission* that decades later became a pillar of the theory of lasers. But the paper had no predictive features.

Newton also wrote a book called *Opticks* which, according to Marjorie Hope Nicolson, inspired sages and poets through the length of the eighteenth century and beyond.[3] Einstein wrote nothing of the kind. The *Opticks* is based on the resolution of white light into the visible spectrum from red to violet, together with related experiments. Newton performed all his experimental feats himself, as did other great physicists after him. Maxwell, for instance, however eminent a theoretician, was also the first professor of *Experimental* Physics at Cambridge University. But Einstein never performed an experiment in his life. Einstein spent twenty-two years at the Institute for Advanced Study, but he never formed a school of modern physics, whereas Niels Bohr directed such a school of world renown.

Einstein never coined an original name for anything. He created the elementary particle "photon," calling it a "quantum of light." The beguiling name *photon* was coined by somebody else. Even his "principle of relativity" was not his by name, but Poincaré's. Heisenberg, at the age of twenty-four or twenty-five, proclaimed an "Uncertainty Principle" that scared the daylights out of some philosophers. Einstein never came up with anything so suggestive. I know only one aphorism of his worth remembering: "As far as the laws of mathematics refer to reality they are not certain, and as far as they are certain they do not refer to reality." Interesting as it may be, it does not have half the punch of the cognate saying that "mathematics is the field of knowledge in which nobody knows what it is that he is talking about," which I think is due to Bertrand Russell.

An awareness of the fact that Einstein was, after all, a product of a period is beginning to seep through. The National Academy of Sciences in Washington, D.C., has recently decided to erect an out-of-doors monument to Einstein. I have no quarrel with this at all. Einstein became not only an American citizen, but also an American property. After World War II many immigrant celebrities started dashing about all over Europe, usually ending up in Switzerland, where at that time they could get creature comforts approximating those in the United States. Einstein, however, stayed put in Princeton, officially at any rate, and the community, in all its strata, was very appreciative of this. When he died in the Princeton Hospital, right at home, a blanket of sadness spread over the town. Thus a monument to him is well deserved. But the prospectus of the Academy soliciting contributions towards the erection of the monument is surprisingly circumspect. It bills him as the greatest theoretical physicist of the twentieth century, as if shunning a comparison with a nineteenth-century physicist like Maxwell, or with a twentieth-century scientist other than a physicist—say a Sigmund Freud, who would be formidable competition indeed.

Still, with all possible qualifications duly noted, Einstein was a person of really great impact, not only on physics but also on philosophy, as even a schematic presentation of his achievements ought to put beyond doubt.

Einstein's span of high creativity extended from 1900 till 1920, when he was forty-one, or, if one wants to include the Bose-Einstein statistics, till 1924 when he was forty-five. This seems typically to be the approximate productive span for persons of his caliber. Maxwell died at forty-eight, and Riemann, but for whom there would be no Einstein gravitation, at less than forty. Gauss managed to lay the foundation for Riemann's pre-Einstein memoir when he was approaching fifty. Newton published his *Principia* at forty-five, and his contemporary Spinoza died at forty-five. Galileo crested at the age of forty- six with his *Starry Messenger*, which created the telescopic depth of the universe. His contemporary Johannes Kepler terminated his high creativity with his third planetary law at about forty-seven, and Galileo's and Kepler's contemporary William Shakespeare retired from London to Stratford at forty-eight. Before

Shakespeare, Giordano Bruno was incarcerated by the Inquisition at the age of forty-four; and long before him Thomas Aquinas amassed a shelf of writings amidst an active career in church policy before dying at the age of forty-eight or -nine. There were notable exceptions though: Miguél de Cervantes, a contemporary of Shakespeare, was already fifty-eight when the publication of *Don Quixote* plunged him into immortality. Also, Immanuel Kant of Königsberg was about fifty-eight when the publication of the *Critique of Pure Reason* made him a successor—some would say *the* successor—to Plato of Athens.

Einstein's creative span from 1900 till 1920 is neatly divided in two halves by the First Solvay Congress of 1911. These Congresses, founded by the manufacturer of sodium carbonate Ernest Solvay, meeting in Brussels, and having about twenty-five participants each, are resplendent with famous names, and the first was particularly star-studded. Einstein, at thirty-two, was the youngest participant, and James Jeans, at thirty-four, the next youngest. These two "juniors" were charged with reporting on the bad state of health of the Dulong-Petit Law about specific heat, with Jeans presenting the patient's past history in the nineteenth century when ministered to by Maxwell and Boltzmann, and Einstein explaining the fancy remedy, quanta and all, prescribed by himself in 1907. It leaps at the reader of the Proceedings of the Congress that luminaries like Lorentz, Poincaré, Planck, Nernst, and W. Wien were profoundly impressed with Einstein, and were so indulgent with him. He talked a great deal, and butted in at will. And the luminaries beamed at him, at whatever he said. In return, Einstein was quite deferential in letters to them (less so in letters about them).

Poincaré died soon after, which made it the easier for Einstein to outshine the others within a decade, shining them out of existence, as it were. In a way, they did it to themselves. Only two years after the Congress, in 1913, Planck, speaking for the German delegation to the Congress, told some Prussian authorities that Einstein was a physicist in a century, and *must* be brought to Berlin. He was made both a salaried member of the Prussian Academy of Sciences with the privilege of lecturing at the University (the two buildings are, or were, close by) and the director of a separate research Institute of Physics whose creation was hastened by his appointment. All this at the age of barely thirty-five, in the spring days of 1914 before the outbreak of World War I, even before Einstein was ready to present his *pièce de résistance*, the theory of General Relativity and Gravitation, which, incidentally, as some rumor had it, Planck abhorred.

Einstein did indeed lecture at the university, making it a platform for the propagation of the faith in relativity and himself. I attended such a lecture in 1919, sixty years ago, and I vividly remember part of what he said, and certainly how he said it. From time to time, in any lecture or debate, he would

look up above the audience, as if actually communing with the powers above, but letting the audience be witness to it.

In content, what I remember most about the lecture was a sharp upgrading of the stature of Michael Faraday. Nowadays there is a Newton-Faraday-Maxwell axis, and I think that Einstein contributed greatly to its creation. At the beginning of the century Faraday was not included in such an exalted company. Even in the late 1930s an Oxford don, a humanist visiting the Institute for Advanced Study at Princeton, told me how enlightening it was for him to learn in Princeton of the great esteem that Faraday enjoyed in the U.S.A. Einstein in his lecture gave Faraday much credit for the creation of the electromagnetic field, even if the lines of force in the field had the material quality of strings or even cables for him.

But now for Einstein's real achievements.

In 1905, at twenty-six, he published, in one and the same volume of the *Annalen der Physik*, three papers, each now enshrined in fame. In the first paper he introduced, but for the name, the universal *photon* as an elementary particle much as it is understood today. Its only rival was the electron, which, although long known, had been institutionalized as a kind of elementary particle in our present-day sense about ten years before. The most notable point of the paper is that Einstein satisfactorily explained the way in which these two rivals interact in the so-called photoelectric effect. It was this paper that brought Einstein the Nobel Prize in 1921; at least, no other achievement is singled out in the citation. Using the technique of this paper, Einstein began in 1907 to repair the Dulong-Petit law. He carried the repair only halfway, Einstein himself pointing out an imperfection. Debye and others completed the job.

In the second paper of the same volume of the *Annalen*, and in some follow-up papers, Einstein gave a satisfactory theoretical account of Brownian motion, which is the random motion of particles suspended in liquids. The magnitude of this achievement is not dimmed by the fact that, independently of Einstein, Marian Smoluchowski[4] in Cracow did something similar at the same time, and that subsequent theories of Brownian motion, some quite elaborate, were on a different level of mathematical expertise.

The third paper in the volume was the noisily celebrated special theory of relativity—universally celebrated, that is, till 1953, when Edmund Whittaker, in a masterful history of physics, rudely stripped the paper of celebrity and reduced it in rank to a glorified footnote to what Whittaker called "the theory of relativity of Poincaré and Lorentz"; but in the matter of general relativity and gravitation he left Einstein's standing intact, offering, in fact, an excellent sketch of the theory. The anguish of Einstein partisans notwithstanding, most physicists are tending to acknowledge that Whittaker is not entirely wrong, at least in the sense that there were several originators of the theory and that Einstein was a relative late-comer.

For my part, I do assign to Einstein an outstanding share in the discovery of special relativity, because Einstein's paper contained a philosophical blockbuster that had a very salutary effect when it exploded, somewhat belatedly in 1919, on the agora of philosophers and bystanders. It was the philosophical question of what it means to say that two events at different locations in space are synchronous, and how one "verifies" this, the matter of verification being of course the heart of the question.

Surprisingly, philosophers did not resent the intrusion onto their turf by a professional outsider. Many of them were exhilarated, on the Continent at any rate. None dared to spurn it, "lightweight" as it was when compared to customary "heavy" stuff like ethics, aesthetics, mind-and-body, existence of God, transcendental knowledge, etc. Some of them might even sneak Einstein's question into their so-called "Introduction" to philosophy, a grab-bag of what a budding philosopher ought to become familiar with. Einstein's kind of question was not quite unprecedented. Immanuel Kant once asked whether it is meaningful to say that a treasure is buried in the Sahara in a location inaccessible to humans. But these were marginal questions in exotic settings. Nothing can be more common than wanting to know whether two events in different cities have occurred at the same time, however, and, if they have, wanting to establish this in a manner that will stand up in court.

I can cite a witness to the impact of the question. It is Sir Karl Popper, widely known for his book *The Open Society and Its Enemies*. I remember reading in an autobiographical account of his that it was Einstein's special relativity, especially the question of synchronicity, that made him into the philosopher he has become, except that it suited his philosophical temper to feature not "verifiability" but "falsifiability," as a criterion for the validity of any theory, that is.

Formally, special relativity is an alternate to Newtonian mechanics, but different from it. It contains a positive constant c, and Newtonian mechanics arises as a limiting case by letting c go to infinity. By pedigree, however, special relativity was an outgrowth of and even a part of electrodynamics. Lorentz and Poincaré so viewed it, and they included the problem of synchronicity somewhere in their context, as a problem of physics. But Einstein was the first to make it clearly into a problem of knowledge in general. I find that Einstein always thought in this manner. This was his *modus operandi* throughout his entire career, scientific and other, usually for the good, but not always. It made him extremely apt to be successful for the present, but less enduring as a prophet. We will return to this distinction later.

Einstein was what I venture to call an "essentialist." He had the drive and capacity to single out, in any scientific situation under purview, what is really *essential* to the context, not only neutrally, but also in the hierarchical order of its components, and in its scope.

Einstein arrived at the universal photon in this way. The name *photon* was introduced much later, by G. N. Lewis in 1926. As I have already stated, Einstein himself spoke of a "quantum of light," because he sifted its existence out of Planck's quantum theoretic explanation of black body radiation. In fact, in the 1916 paper mentioned before, by penetrating through to essentials, Einstein even gave the simplest proof yet known for Planck's radiation formula from Planck's own premises.

Or, consider the famous formula $E = mc^2$. It was actually found by Poincaré, but presented by him without derivation or explanation. Einstein, however, after proving it, gave it the universal interpretation that if a physical system, any system, loses energy, then it also loses inertial mass. The amount of that loss is E/c^2, with the implied suggestion to a later generation that, conversely, by atomic or nuclear disintegration of mass a corresponding amount of energy can be liberated. This is precisely what happens in atomic fission or thermonuclear fusion. Because of this universal interpretation, which was heavily emphasized in the so-called *Smyth Report*,[5] the formula has been firmly attached to Einstein, irrespective of its origin in Poincaré, who had stated it in an electrodynamic context.

Even Einstein's gravitation theory, his most original creation ever, was not independent of an essentialist provenance, in Einstein's own pedigree for it, at any rate. He packaged it inside something he called general theory of relativity; this in turn was an essentialist elaboration of something called special theory of relativity, which was designed to feature the fact that light velocity is maximal and constant. And this special theory in turn was an essentialist shell in which to house something that had been created by Poincaré, a principle of relativity, expressly so named by him. This principle had its debut right in this country, on September 24, 1904, when Poincaré presented it at a Congress of Arts and Sciences assembled at the World Exposition in St. Louis. As if this route were not devious enough, on the road from the principle of relativity to gravitation Einstein built a major way station called the Principle of Equivalence, and a secondary one, a Principle of Covariance, both mandatory stopovers; the stopover at Equivalence involved an eerie plunge in the so-called Einstein Elevator.

All this sounds very involved. Nevertheless, the magnitude of Einstein's achievement is such that it can be savored from outside without entering into a maze of technicalities at all.

Gravitation is the oldest and most ubiquitous phenomenon, and it is always accessible to observation. Objects are falling and moving all the time and in all places. But explaining gravitation has always been a forbidding problem. Even today the innermost structure of gravitation is more arcane than anything else in physics, and if you overhear a physicist say that something is only *probably* so, then more likely than not he is talking about gravitation, or something involving gravitation. Thus, some physicists say

incessantly that there "probably" are gravitons (elementary corpuscular particles of gravitational *force*), as if by saying this often enough the gravitons would indeed show up suddenly.

Aristotle proposed a theory in which each body in the universe has its natural place, and if it is not located in it, it seeks to reach it. There was no effective rival theory till the end of the sixteenth century, although dissatisfaction with Aristotle's theory had been on the increase since the late Middle Ages. In the early seventeenth century Galileo offered a satisfactory explanation, but only for terrestrial events. His paths of falling bodies were even parallel, as if the earth were flat. At the same time Kepler was seeking to explain gravity's cosmic manifestations. With his powerful intuition he half-guessed the three planetary laws, but an underlying rationale eluded him. Newton then found one, on a comprehensive scale.

The simplicity and grandeur of Newton's theory fascinated lay intellectuals like Voltaire and unemotional philosophers like Kant. But professionals in astronomy and mechanics had cause to view it soberly, even disenchantedly. When trying to regulate the motions of planets, moons, and comets by the new theory, they encountered difficulty after difficulty. As soon as one difficulty was seemingly over, a new one demanded attention. Therefore there were no discouraging side-glances at Einstein when—after some attempts by others—he started from the very roots, building up something very different, even if it was in close proximity to Newton's ideas.

From our retrospect, the working mathematics needed for any mathematically controlled theory of gravitation was in Newton's time still in its infancy, and there was only one space form available in which to create it, the Euclidean. That was all that Newton had to work with, and he made the most of it. Euclidean space happens to be infinite by well-intuited mathematical notions of infinitude. But this does not mean, as some philosopher-historians volubly proclaim, that Newton was intellectually motivated by a metaphysico-theological drive for infinitude of space. Even the fact that Newton viewed his Euclidean space as "absolute" has no such implication for me. If closed Riemannian space had been mathematically accessible to Newton and he had used such a space instead of the standard Euclidean type, then philosopher-historians would have undoubtedly adjusted his alleged metaphysico-theological drive accordingly.

From motives that nobody can fathom, after 1911 (and even earlier) Einstein was driven to erect a theory of gravitation of his own, a genuinely new one. By chance and circumstances he fell in with a body of elaborate mathematics that had come into being long after Newton, in the course of the nineteenth century. As if by a predestined harmony, it was highly fit to articulate Einstein's desiderata from physics and give suitable responses to them. It was the so-called Riemannian geometry, that is, the multidimensional differential geometry mainly of Riemann, but indispensably also of Christoffel,

Beltrami, Ricci, and Levi-Civita. The mathematician Marcel Grossmann, an old acquaintance of Einstein's and a faculty colleague at Zurich, was Einstein's mentor and even co-author in a few papers. But the final theory, and above all the inspiration, drive, and passion of purpose, were wholly Einstein's. At any rate, there are no reports of Grossmann having had the sense of a brush with immortality followed by failure due to Einstein's ill-will. Einstein did exhaust his store of mathematical knowledge, but any physicist has the privilege of doing so with any mathematician. Einstein was after big game, and he applied whatever hunting laws were legitimate.

When mathematicians became aware of this activity in a highly charged mathematical area, their curiosity was aroused, and David Hilbert, the greatest among them, set out to rob Einstein of his prey. In defense, or rather counter-attack, Einstein tore the center piece out of his kill, left the denuded carcass for mathematicians to argue over, dashed off into the promising field of cosmology, and very quickly inaugurated a novel kind of cosmological speculation of which he became the father or godfather for the rest of the century. This was a glorious evasive tactic, and it was Einstein's all-overshadowing enterprise, uniquely his, although mathematicians hesitated to follow Einstein, and even physicists were skeptical. I heard it said that Niels Bohr warned his followers to stay out of cosmology until problems of microphysics have been solved. This is like saying that one should defer space exploration until urban slums have been cleared.

Again, the effect of these developments on philosophy was incalculable. Since Giordano Bruno in the sixteenth century, the space problem involved in astronomy and cosmology was philosophically beset by an utterly sterile yes-or-no question: whether space is finite or infinite and also what infinitude of space means cognitively. Some philosophers of science are clinging to this question even today. Aristotle was naively condemned for finitude, and Bruno was even more naively hailed for infinitude. Those in the know, the true cognoscenti, were mostly hedging. Copernicus hedged—and this was one of his finest features; and so did Galileo, from indecision. Kepler inclined towards finitude, but less from siding with Aristotle than from disapproving of Bruno, whose brand of infinitude he considered astrophysically reckless, and rightly so. Descartes created his own wrinkle and hedged by making his so-called extension (*extension, étendue*) neither finite nor infinite but indefinite, which, in its inventiveness, went back right to Anaximander. Newton in the *Principia* was fully hedging, avoiding a decision throughout the three editions. When the rector Richard Bentley in a pesky letter tried to force Newton's hand by making him agree that a universe of finite matter might suffer gravitational collapse, Newton hemmed and hawed and counter-suggested that such a universe might remain stable by arranging itself in what is nowadays called gravitational clustering. And Immanuel Kant weaseled out of the situation some of the time by devising an antinomy that if the world

is infinite it is finite, and if finite infinite. Among medieval schoolmen such antinomies must have been quite common. Any trained schoolman could probably make up one on any contrariety offered. Kant himself used several.

To my surprise, Ludwig Wittgenstein was quite conventional in this matter. The logical space of his *Tractatus* is, by parenthetic remark, infinite. Commentators notwithstanding, this infinitude serves no purpose, but is the standard philosophical presumption since Giordano Bruno.

Einstein changed all this by abolishing the traditional presumption that the universe is the infinite Euclidean space or a finite portion of it. Instead he approached the outlook of Riemann that almost any topological manifold should be eligible to begin with. A compact manifold, for instance, offers a neat compromise between finite and infinite, and Einstein gave attention to the simplest such case, namely, the case of a sphere. Also, it is not necessary to elect one fixed space and adhere to it. One may envisage a family of spaces and examine how observational and speculative data are compatible with all of them or some of them. As a consequence, even the problem whether the universe had an origin in time, in a cosmically meaningful gauge of time, or has been in an eternal state of existence, appeared in a very new light. All in all, as I remember it, one felt one was finally free after centuries of constriction in a straitjacket of presumptions.

Of course, curved spaces were introduced in the nineteenth century, long before Einstein. However, the renowned hyperbolic space of Bolyai-Lobachevsky is topologically not different from Euclidean space and made no immediate impression on physics, or even on mathematics. But the elliptic space of Riemann did draw a quick response. Soon after Riemann's memoir became known in English, Simon Newcomb, whom I have previously mentioned, in an 1877 paper in the prestigious *Crelle Journal* speculated on how elliptic and even projective space would be detectable by human or astronomical experience. Also, in 1900 an astronomer, Karl Schwarzschild, went into greater quantitative detail. Yet these papers were of no enduring consequence, because they dealt with the same physics as before, only in different spatial frameworks. But in 1916 the same Schwarzschild, in response to the latest work of Einstein, constructed a relativistic space-time model whose importance is such that Schwarzschild's name, I think, currently occurs in cosmology more frequently than Einstein's. Regrettably, he died soon after, at the age of forty-three.

A similar early contribution to relativity was made by Willem de Sitter. In addition to scoring specific achievements, he also wrote in 1932 a small general book called *Kosmos*. In it he makes a statement that should be emblazoned on all books in physics or astronomy. It is the statement that "Infinity is not a physical, but a mathematical concept."[6] That is, whenever you state in exact science that some physical magnitude is infinite, then, without exception, you refer to a quantity in an appropriate mathematical

skeleton of the physical context. Without a mathematical skeleton, however primitive it be, no such statement can be made. This in itself does away with many a version of the query whether the universe is finite or infinite.

In comparison to Einstein's gravitation, Newton's appears to be simplistic. But it is wrong to say that Einstein "overthrew" Newton. Einstein used mathematical resources, readied by others, that would have been inaccessible to Newton in his wildest dreams. Newton was still so ingenuous in the ways of analysis that he took it for granted, half-apologetically, that his gravitational force was an action-at-a-distance, not knowing that the simple analytical device of introducing the gravitational potential turns it into a proximity-action, instantly. In fact, the gravitational potential as a dominant concept revealed itself only in the early nineteenth century in the work of Poisson. Einstein himself stated very expressly that, *mathematically*, what he did was to replace Poisson's one-component-object by a more elaborate object of ten components.

Einstein's advance over Newton was evolutionary, and nothing but evolutionary. He overthrew Newton as little as did birds overthrow reptiles out of whom they evolved. In fact, reptiles continue to flourish alongside birds, as does Newton's gravitation alongside Einstein's, for instance, in all engineering mechanics and physics in our time. The theory and production of high velocity particles prerequires special relativity, but particle accelerators in which they are generated are architecturally built on Newtonian engineering mechanics exclusively. As Niels Bohr put it in general terms: "No more is it likely that the fundamental concepts of the classical theories will ever become superfluous for the description of physical experience."[7]

Einstein did not overthrow Maxwell either. In fact, it can be argued that special relativity was an apex achievement evolving almost rectilinearly out of Maxwell's electromagnetism, and all but completed it.

Nor can it be maintained that Einstein was superior to Maxwell in an overall sense. It is true that, except for his study of the ring of Saturn, Maxwell did not contribute directly to the study of gravitation in which Newton and Einstein excelled. But he did perform the extraordinary feat, to which there is no parallel, of fusing optics with electromagnetism. Optics, Aristotle's *hé optiké*, was the most venerable body of knowledge there was, and everybody who was somebody, literally everybody, felt bound to have an outlook on it—physical, philosophical, even inspirational—in late antiquity, the Middle Ages, the seventeenth century, the eighteenth century, etc. Electromagnetism, however, William Gilbert notwithstanding, was an upstart field; the Leyden jar was the perennial toy for adults. Yet Maxwell fused these two fields into one, or, at any rate, consummated their fusion. In the process he created, with posthumous assistance from Hertz and others, the awe-inspiring electromagnetic spectrum from end to end, from frequency 0 to frequency ∞. To appraise its importance one need only consider what would be left of laboratory physics, red-shift cosmology, and radio-astronomy if it were not available. To offset this achievement Newton at least wrote his two tremendous works, the *Principia* and the *Opticks*, on which Voltaire could compose a beguiling commentary. Einstein wrote nothing to induce Arthur Koestler to include him among his sleepwalkers.

Any survey of Einstein's scientific career, however sketchy, must also take into account activities in his later years, after the high creativity had exhausted itself, but the glory and the presence remained. His scientific later years lasted at least three decades, beginning not later than 1925, although he continued to bask in glory for another ten years or so before gradually becoming an "institution" resting on past achievements.

Einstein's later years had a regrettably negative scientific cast. If, as I have maintained all along in this essay, the nineteenth century lasted from the French Revolution and Napoleon till the end of World War I, then, in physics, Einstein was a perfect embodiment of the last two decades of it, shining brilliantly forth into the twentieth century that came afterwards, but not being able to see into it himself, as if the light that he threw into it flashed back at him, blinding his vision. In this sense Einstein was a person of the present, of the lived present and the escapist present, and it was this that made him, especially in this country, a smash hit of the 1920s.

But he was not a prophet; he did not have the passion and vision, selflessness and calling, to be one. Between 1925 and 1927, a crew of post-teenagers, headed by Heisenberg, Schrödinger, and Dirac, seized the helm of the ship of quantum theory, set out into uncharted waters, and, to the amazement of many, started making discovery after discovery, not only of islands, but even of continents, and of new navigational principles too. This was the so-called new quantum theory. Mathematically, the "classical" equations of mechanics and electrodynamics that had emerged from the work of Newton, Euler, Lagrange, and Maxwell were radically re-interpreted, and the effect on the open mind was compelling and irresistible.

Einstein, amazingly, resisted and remained aloof. He soon became antagonistic to the new discoveries, and gradually more rejectionist. He could not or would not perceive that a momentous development in a new phase of modernity was in the making. He refused to legitimize it, in whole or in any part, and stuck to his refusal to the end, pleas by personal friends notwithstanding. There were no overt public demonstrations, no excommunications of heretics, just a hard standoff, and an agreement to disagree reluctantly maintained.

There were debates, though. Einstein, being unbeatable in debates, scored on points, sometimes markedly. And like a medieval schoolman, he was content with this kind of victory and the applause of his retinue. But, before the God of Physics, his were illusory victories. The new quantum theory was couched in a new idiom, subdivided into dialects. Its grammar is not yet settled, even today, to the satisfaction of all the faithful. This bespeaks strength,

not feebleness. For instance, analysis was a new idiom for mathematically controlled science. It suddenly sprang up close to 1600, and immediately came up with Kepler's remarkable planetary laws. But it went through the pangs of birth, childhood, and adolescence for over two centuries before reaching the adulthood of rigor and consistency in the nineteenth century, and at first it had many more vulnerabilities than anything that Einstein could adduce against the innovations of his day. One can only pity a twentieth-century student of Kepler bent on making twentieth-century sense out of the ramblings of Kepler's *New Astronomy*. Yet the achievements of Kepler are here to stay. Einstein should have known that a debate or two will not topple something destined to stay, but, alas, he did not. Whether he could not or would not know it is hard to determine, and does not make a great difference anyway.

There were specific findings to which Einstein and a small band of other physicists were dialectically opposed, as some still are. The primary one is Heisenberg's Uncertainty Principle taken in conjunction with Born's probability doctrine. It states that in the case of an elementary particle, say an electron, its position and its momentum (that is, velocity) cannot be, both of them, observed with sharp precision at the same time. If, say, the position has been fixed absolutely, then the momentum is entirely random; joint approximations of the two have thresholds beyond which they cannot be improved, every threshold involving Planck's constant of action; and if one of the two has been observed to fall within a certain range, then the value of the other has possibilities that are given by associated probability distributions.[8]

These assertions about limitations of microphysical observability produced in Einstein and a handful of other physicists an emotional reaction as if a sacrament hallowing the concepts of space and time had been defiled. Also, pragmatically Einstein must have instantly perceived that this was the end of his dream of a Unified Field Theory *on his terms*, although for years on end he would go through the motions of trying to find one; and it was perhaps this that he would not ever forgive. While only some scientists balked, many more philosophers were dismayed. Until 1927, when Heisenberg proclaimed his Uncertainty Principle, professional philosophers took little notice of quantum theory, of the "old" theory and even the "new" one. But this apparent contravention of the customary presumption of determinism in the laws and prescriptions of physics took them by very unpleasant surprise and jolted them into attention. It was one thing say, to oppose Hegelianism to Kantianism, old or "neo-"; but it was quite another thing to call nineteenth century determinism into question. An Einstein could afford just to stand aside and pout. The philosophers could not. They had to get into the scrimmage and try to explain things to themselves and others. For instance, Popper wrote a lengthy article about it, and the distinguished philosopher Ernst Cassirer, author of a string of important works, added one last book to his list, to deal with determinism and indeterminism in physics. From what I have seen, these philosophers' cogitations have not been overly illuminating so far.

From my viewpoint, their lack of success does not reflect on the new physics or the struggling philosophers, nor does it justify Einstein's aloofness. The new quantum theory is finally a creation of the twentieth century proper. It expresses the vicissitudes and anxieties, the fears and uncertainties of our age much more faithfully than did the old theory, and professional philosophy will have to find the drive and the idiom by which and in which to articulate this.

The nineteenth century knew a great deal about discontinuities, and it spiced the naiveté of the eighteenth century by inserting "additives" of discontinuities, some good-sized, into its philosophemes about continuity all around. But these added discontinuities were somehow felt to be undesirable, even if ineluctable, and continuity remained the paramount wish and expectation, even more intensely than in the eighteenth century. In fact, academics have been wont to proclaim that the nineteenth century was *the* century of continuity. Although Darwin's continuist evolution had to be salvaged from immobilizing rigidity by an injection of potent mutationist discontinuity, overall continuity nonetheless remained paramount. Bernhard Riemann, one of the gentlest of men, in a paper of 1860 inaugurated thought patterns and even words of violence that only twentieth century technology was able to follow up. He did not have "shock wave" in his vocabulary, but he had "compression wave" (*Verdichtungswelle*) and "compression thrust" (*Verdichtungsstoss*); yet the world around him took little notice of his anticipation. Karl Marx envisaged a violent socioeconomic upheaval, that is, discontinuity, to come. But it was sociopolitically predetermined and bound to be followed by a future free of such discontinuities. And Marx bitterly fought anarchists, that is, advocates of political discontinuity as a way of life.

But as the twentieth century wanes, discontinuities are gradually advancing to a level equal in day-to-day importance to that of continuities. They are becoming severally and jointly a way of life and thought throughout, and not only in select areas. Einstein had no qualms about imputing to elementary particles two co-existent aspects, a continuous undulatory aspect and a discontinuous corpuscular aspect. And he had no objection to, but productively cooperated in the large nineteenth-century statistical theory of matter that takes into account the difficulties of truly precise observations and the mathematical inconvenience of dealing rigorously with a mechanical system of many particles. But he balked more than half of his academic life at the Born-Heisenberg statistical theory, because its statistical aspect is not marginally approximative but centrally legislative.

And yet, already decades before Born-Heisenberg, the American philosopher Charles Sanders Peirce (1839-1914) perceived, from pure thinking as it were, the possibility of an "absolute chance," that is, of a genuine indeter-

minacy as opposed to an indeterminacy arising merely from "ignorance," be the ignorance genuine or presumptive. Peirce even installed the minor Greek goddess *Tyche* (chance) to be in charge of this "Tychism."[9]

Niels Bohr, only six years younger than Einstein, proposed to come to grips with the perplexities of twentieth-century physics by the use of a new rule of comprehension, a tricky one. He called it the principle of complementarity. By this principle there are near-contradictory aspects in the process of verifying phenomena. Yet, however contradictory, the aspects complement each other. If an experiment illumines one aspect it necessarily obscures the other. On translating from experimentation to cogitation it follows that there are theories that are both contradictory and complementary.[10] As if to corroborate this, there are physicists who find that relativity theory and quantum theory are of this kind.

This sort of thinking was outside Einstein's horizon. Before World War I certain intellectual circles hopefully expected that a common language of communication, a true Esperanto, would cure many if not all ills of the world; and Einstein's heart was arrested in this expectation. But it is a vain expectation. In our century there is a built-in possibility for ambiguity and uncertainty that cannot be eliminated. Gödel's theorem, when boldly transferred from Logic to Life, already points to this, whether Gödel himself would approve of such a transfer or not. Suppose the United States and Russia would agree, in the purest of intentions, to draw up a detailed comprehensive document of coexistence in the most precise language possible. By Gödel's theorem no precaution of wording can prevent situations from arising about which it could not be decided whether they are or are not subsumable under the provisions of the document. An equally bold transfer of the principle of complementarity suggests that subsumability in all cases could be insured by composing the treaty in two versions, English and Russian, but at a price: The price is that in some instances conflicting interpretations might arise, either outright contradictory, or differing so much in degrees of clarity as to amount to a contradiction. Albert Einstein, physicist *sans pareil*, could not or would not see what was quintessential in the workaday doings of a younger generation of physicists all around him.

Bertrand Russell, with whom Einstein was in rapport, was not far different from him. Russell's great disciple Ludwig Wittgenstein did have a sense of something new in the offing. His *Tractatus* was done at the same time as Einstein's work on General Relativity, and fits snugly into the outgoing phase of the extended nineteenth century. After that, Wittgenstein began to grope for something radically different, towards entering into the twentieth century proper, as I see it; this is shown by the difference of style in his *Philosophical Investigations*, and in the *Brown* and *Blue Books* before. But he could not make it. His intellectual resources were too limited and too exhausted for such a radical reorientation.

Kafka and other existentialists, with the Sigmund Freud of around 1930 among them, did show an awareness of a rising Discontent in Civilization, but they were too continuity-bound, too conditioned and too overwhelmed by the past effusions of Schopenhauer, Kierkegaard, and Nietzsche, to recognize the twentieth-century novelty of it all.

Even Arnold Toynbee, when he tried to extrapolate from the past into the future, did not have things in focus. Too much eschatological mysticism clouded his vision. But his rival prognosticator Oswald Spengler, author of *The Decline of the West*, clearly described the woes of our "imperial presidency," for instance, and he clearly foresaw the oncoming struggle between the West—which he calls the Faustian culture—and a resurgent Russia. What is more, he insisted before 1918 that in the end it will be not the Lenins but the Solzhenitsyns that will oppose us.

The contrast between the nineteenth and twentieth centuries can be epitomized by a changing of the guard in *Central Europe*, and I mean Central Europe literally. In the extension of the nineteenth century there were Freud, Einstein, Spengler. Their counterparts in the twentieth century proper were Kafka, Heisenberg, Gödel. Overwhelming as the nineteenth century is in this confrontation—and it was an overwhelming century indeed—the twentieth century does have a very distinctive composition and orientation of its own, a radically different one. How the twenty-first century will compare with the two preceding ones will be for the twenty-first to decide.

NOTES

1. Albert Einstein was born March 14, 1879, in Ulm, Germany, and died April 15, 1955, in Princeton, New Jersey. He was cremated and his ashes were scattered, except for the brain, which has been preserved.

After an irregular attendance at high schools in Munich, Germany, and Aurau, Switzerland, he was enrolled at the reputed Zurich Institute of Technology ETH (Eidgenössische Technische Hochschule) from July 1896 till August 1900, graduating from its Division IV with a diploma for teaching mathematics and physics. After temporary teaching jobs he became on June 23, 1902, a clerk at the Patent Office in Bern, from which position he resigned October 15, 1909, to become an associate professor (Extraordinarius) at the University of Zurich. Until joining this university, while still with the Patent Office, he was also a *Privatdozent* at the University of Bern. He left the University of Zurich in the summer of 1911, to become professor at the German University of Prague. He stayed only one year, 1911/1912, leaving to become full professor (Ordinarius) at the ETH, upon the recommendations of Marie Curie and Henri Poincaré. This stay was also brief, and from April 1, 1914, till the middle of March 1933 he was a salaried member of the Prussian Academy of Sciences in Berlin. In October 1933 he reached his final academic destination. He joined the Institute for Advanced Study at Princeton, New Jersey, as one of its faculty members, becoming a resident Emeritus in 1946.

These data are taken from Max Flückiger, *Albert Einstein in Bern* (Bern, 1974), and the comprehensive biography of Einstein: Ronald W. Clark, *Einstein, the Life and Times* (New York and Cleveland: World Publishing Company, 1971).

Some data in the text have been taken from the bibliography in P. A. Schilpp, *Albert Einstein, Philosopher-Scientist* (Evanston, Ill., 1949); from Jagdish Mehra, *The Solvay Conferences on Physics* (Dordrecht and Boston, 1975); and from A. Eucken, *Die Theorie der Strahlung und der Quanten* (Halle, 1914), which is a detailed report on the First Solvay Conference.

2. *Science* **49** (1929): 248-249. Einstein observes that, whatever Newcomb achieved, he could of course not explain the irregularity of the perihelion of Mercury because only General Relativity could cope with this anomaly. In an assessment of Newcomb's achievements this was an odd observation to make, since Newcomb died in 1909, years before there was a theory of General Relativity. Newton could not have explained it either.

3. Marjorie Hope Nicolson, *Newton Demands the Muse: Newton's "Opticks" and the Eighteenth-Century Poets* (Princeton, 1946). See also the "Preface" by I. Bernard Cohen in the edition of the *Opticks* by Dover Publications (New York, 1952). This edition also has a valuable introduction by Sir Edmund Whittaker.

4. Died at age forty-five.

5. H. D. Smyth, *Atomic Energy for Military Power* (Washington, D.C., 1945). This book, a best-seller, was, in effect, a government publication.

6. W. de Sitter, *Kosmos* (Cambridge, Mass., 1932), p. 113.

7. Niels Bohr, *Atomic Theory and the Description of Nature* (Cambridge, 1934), p. 16.

8. Ibid.

9. Salomon Bochner, "Mathematical Reflections," *The American Mathematical Monthly* **81** (1974): 827-857, especially p. 850.

10. Bohr, *Atomic Theory*, pp. 1-20.